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Demonstration of Thermophilic Aerobic-Anaerobic Digestion at Hagerstown, Maryland.

Union Carbide Corp., Tonawanda, NY

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DEMONSTRATION OF THERMOPHILIC AEROBIC-ANAEROBIC DIGESTION AT HAGERSTOWN, MARYLAND

by

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in cooperation with the
Water Pollution Control Department
Hagerstown, Maryland

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U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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16. ABSTRACT

This report describes the successful operation of a new and novel approach to digestion of sludge at the Hagerstown wastewater treatment plant. The process, known as dual digestion, involved the coupling of a full-scale experimental aerobic reactor to an existing full-scale anaerobic digester for the treatment of Hagerstown's raw sludge. In the process, sludge is aeraobically digested at thermophilic conditions, using pure oxygen for about one day, followed by a longer period of 8 to 16 days of mesophilic (or thermophilic) anaerobic digestion. The system handled 16,400 gallons of raw sludge per day with average autothermal temperature in the aerobic digester of 51°C. Pathogen analyses of the raw and digested sludge samples indicated the process significantly reduced pathogen levels beyond that achieved by conventional anaerobic digestion practice. The dual digestion process proved itself to be an effective sludge stabilization process achieving an overall volatile solids destruction of 42 percent.

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Sludge treatment Aerobic Digestion Anaerobic digestion Oxygen Pathogen inactivation Energy saving		

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solids and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This research study emphasizes the benefits that can be derived from the aerobic digestion of sludge with pure oxygen. It provides the means to use the heat of reaction to stabilize the sludge even during very cold ambient temperatures. It also reduces pathogen densities thereby making the treated sludge more amenable to land applications.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

A thermophilic aerobic-anaerobic digestion system was designed and constructed at the Hagerstown, Maryland Wastewater Treatment Plant. This project establishes the process performance of this dual digestion system in a full-scale design. The system included a short retention-time (approximately 1- day) aerobic digester followed by a high rate anaerobic digester. Approximately 16,400 gallons per day of thickened, air-activated sludge was autothermally heated by aerobic oxidation of organic substrates in the first step and then anaerobically digested in the second step, with the formation of methane gas. Data were collected to evaluate the system's performance regarding volatile solids destruction, oxygen consumption, power draw, heat production, pathogen reduction and process stability.

Thermophilic temperatures (greater than 45°C) were rapidly achieved upon start-up of the dual digestion system and were maintained in the aerobic reactor at a hydraulic retention time of approximately 1 day. The high shear aeration device demonstrated sufficient oxygen transfer capacity to achieve and maintain these high temperatures at power densities of 0.5 to 1.1 shaft horsepower/1000 gallons* and high purity oxygen feed flows of 10-33 CFM-NTP in the aerobic reactor. The system responded well to variations in feed flow and solids concentration as well as operational upsets. Analyses were performed that illustrate the capability of the dual digestion system for achieving significant reductions in the level of pathogenic organisms in sewage sludge. Finally, over the course of some 20 weeks of operation the dual digestion system proved itself an effective sludge stabilization process, achieving an overall volatile solids reduction of 41.6 percent.

This report was submitted in fulfillment of EPA Grant No. S-805823-01-0 by the City of Hagerstown, Maryland, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period June 11, 1980, to January 21, 1981, and work was completed as of January 31, 1981. The report was prepared by Union Carbide Corporation.

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* Non-metric units of measurement are used at various points throughout this report to be consistent with instrument readings. A conversion table to the International system of Units is provided for convenience on page viii.

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CONVERSION TABLE

UNIT	MULTIPLY BY TO GET	S. I. Unit
Atmospheres	101,325	newtons/m^2
BTU	1055.1	Joules
BTU/day	0.29288	Joule/second
BTU/hour	0.012203	Joule/second
BTU/hour ft^2 °F	0.176118	Joule/sec m^2 °K
BTU/hour ft^2/in°F	6.9348	Joule/sec m °K
BTU/lbm	2326	Joule/Kg
BTU/lbm °F	4186.8	Joule/Kg °K
BTU/lb mole	2.3244	Joule/gm-mole
CFM-NTP	0.0263	m^3(STP)/second
days	0.000012	second
gallons	0.003785	m^3
gallons/day	0.0438×10^{-6}	m^3/second
gallons/hour	1.0515×10^{-6}	m^3/second
gallons/day. ft^2	0.4715×10^{-6}	m/second
grams	0.001	Kg
hour	0.000278	second
horsepower	745.7	Joules/second
inches	0.00254	m
kilowatts	1000	Joules/second
liter	0.001	m^3
million gallons	3785	m^3
million gallons/day	0.0438	m^3/second
milligrams/liter	0.001	Kg/m^3
milligrams/Kg	1×10^{-6}	Kg/Kg
milliliters	1×10^{-6}	m^3
millimeters of Hg	133.32	newtons/m^2
pounds	0.45359	Kg
pounds/day	5.25×10^{-6}	Kg/second
pounds/pound-mole	1.0	grams/gram-mole
pound-moles/day	0.00525	gram-mole/second
revolutions/minute	0.0167	revolutions/second
square feet	0.0929	m^2

°K = °C + 273
°K = (°F − 32)(5/9) + 273

LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

ATM -- atmosphere pressure
Btu -- British thermal unit
BVS -- biodegradable volatile solids (mg/l) or (fraction)
CFM -- cubic feet per minute
CFM-NTP -- cubic feet per minute at 70°F and 1 ATM
COD -- chemical oxygen demand
CSTR -- continuous stirred tank reactor
g -- gram
gal -- gallon
g/Kg -- grams per kilogram
GPD -- gallons per day
gpd psf -- gallons per day per square foot
GPH -- gallons per hour
hp -- horsepower
hr -- hour
Kw -- kilowatt = 10^3 watts
l -- liter
lb -- pound
LEL -- lower explosive limit (hydrocarbon)
LHP -- line horsepower draw
MG -- million gallons
MGD -- million gallons per day
mg/Kg — milligrams per kilogram
mg/l -- milligrams per liter
ml -- milliliters = (10^{-3}) liters
M.L. -- mixed liquor
MPN -- most probable number
PFU -- plaque forming units
RT -- retention time (days)
rpm -- revolutions per minute
SHP -- shaft horsepower draw (electrical power input)
t -- time (days)
TKN -- total Kjeldahl nitrogen (mg/l)
TS -- total solids (mg/l) or (%)
VS -- volatile solids (mg/l) or (%)
VS_R -- fractional reduction in volatile solids

SYMBOLS

Asi -- area of reactor surface (ft^2)
°C -- temperature in degrees Celsius
$CaCO_3$ -- calcium carbonate
CH_4 -- methane
CO_2 -- carbon dioxide
Cpi -- heat capacity of gas component i (Btu/lbm °F)
Cpl -- heat capacity of liquid (Btu/lbm °F)
°F -- temperature in degrees Fahrenheit
FA -- gas feed flow (lb moles/day)
Fo -- gas feed flow (lb mole/day)
Fv -- gas vent flow (lb moles/day)
H_A -- heat loss to surroundings (Btu/day)
H_B -- heat generated by biological oxidation (Btu/day)
H_G -- sensible heat loss in aerobic vent gas (Btu/day)
hi -- inner surface film coefficent (Btu/hr ft^2 °F)
H_1 -- sensible heat loss in aerobic effluent sludge (Btu/day)
Hm -- heat generated by mixing (Btu/day)
ho -- outer surface film coefficent (Btu/hr ft^2 °F)
H_{TL} -- total heat loss (Btu/day)
Hv -- heat loss due to the vaporization of water (Btu/day)
K1, K2
Ka,... -- thermal conductivity of material 1, 2, a... (Btu/hr ft^2/in °F)
K_D -- kinetic decay constant (day^{-1})
λ -- latent heat of vaporization of water (Btu/lb mole)
Mi -- molecular weight of component i (lbs/lb mole)
N_2 -- molecular nitrogen
NH_3 -- ammonia
O_2 -- molecular oxygen
Pe -- equivalent pressure (ATM)
pH -- negative logarithm of hydrogen ion concentration
QG -- gas flowrate (CFM-NTP)
O_L -- liquid flowrate (GPD)
T_A -- ambient temperature (°C)
T_E -- aerobic vent gas temperature (°C)
To -- feed oxygen temperature (°C)
T_R -- aerobic reactor temperature (°C)
Ts -- feed sludge temperature (°C)
Usi -- heat transfer coefficient of reactor surface i (Btu/hr ft^2 °F)
VP -- vapor pressure of water (mm Hg)
% VS_R -- percent of volatile solids removed
X1,X2,
X3,... -- thickness of surface 1, 2, ... (inches)
Y_{Ai} -- mole fraction of gas component i in feed
Y_{Ei} -- mole fraction of gas component i in vent
Y_{H2O} -- mole fraction of water vapor in gas
YO_2 -- mole fraction of oxygen in gas

ACKNOWLEDGMENTS

We would like to thank Mr. M. G. "Mike" McGauhey, Administrator of Water Pollution Control for the City of Hagerstown, Maryland, for permitting us to use their fine facilities and for his active participation in making this test program a success. We would especially like to thank Mr. Rick Thomas, Project Coordinator, Mr. Robert Semler, Plant Supervisor, Mr. Richard Reynolds, and all the Hagerstown Wastewater Treatment Plant personnel who demonstrated a great spirit of cooperation and a great deal of patience throughout the duration of the project. Similarly, the responsible supervision of the Hagerstown analytical laboratory by Mr. John Leggit is also gratefully acknowledged.

The sound engineering judgment and numerous contributions of Mr. Henry Hulse of Buchart-Horn Consulting Engineers were invaluable to this pioneer design of the full-scale dual digestion system.

Our appreciation is also extended to Dr. Vincent Oliveri of Johns Hopkins University for his invaluable expertise in the field of bacteriological studies.

We would also like to thank Mr. M. J. Stankewich, Project Manager, and Mr. M. A. Miller, Product Manager of Union Carbide Corporation, whose valuable direction was instrumental in the performance of the program and preparation of the report. We are also grateful for the efforts of Mr. R. F. Alessi, Senior Technician, in the daily operation of the system.

Finally, we deeply appreciate the cooperation and guidance provided throughout the program by Mr. B. Vincent Salotto, U.S. Environmental Protection Agency Project Officer.

SECTION 1

INTRODUCTION

The proper treatment and disposal of wastewater sludge has become a problem of increasing concern (and expense) throughout the world.(1) At present, the most widely practiced processes for sludge stabilization are anaerobic and aerobic digestion. Anaerobic digestion, long a mainstay of wastewater treatment plant design, is a low rate process typically operating with hydraulic retention times in the 15 to 30 day range.(2,3,4) An advantage of the anaerobic process is that it requires little mechanical energy input to maintain operation, and in fact produces a combustible gas, methane. On the other hand, aerobic digestion, a relative newcomer, is a faster and more stable process but is very energy intensive.(2,3,4) The dual digestion system, by combining a short retention time autothermal, aerobic first step with a high rate anaerobic second step, provides a novel approach to the biological stabilization of sludge that incorporates the advantages of each traditional method and minimizes their drawbacks. In this process overall residence time is reduced, attainment of thermophilic conditions in the aerobic stage eliminates pathogens and the generation of heat eliminates the need for ancillary equipment required to maintain anaerobic digester temperatures.

Although extensive pilot and bench-scale work has been completed at Union Carbide's Tonawanda Laboratories,(5) the present study represents the first full-scale demonstration of the dual digestion system.

SECTION 2

CONCLUSIONS

Over the course of 20 weeks of operation, the Hagerstown dual digestion system has successfully demonstrated that thermophilic temperatures (greater than 45°C) can be autothermally achieved and maintained in a full-scale aerobic digester at relatively short (0.95 to 2.25 days) hydraulic retention times. Despite wide variations in sludge feed flowrate, solids concentration, and degradability, control of reactor temperature was maintained simply by adjusting oxygen feed flowrate and aerobic reactor retention time.

Observed volatile solids (VS) removals, oxygen consumption, and heat of reaction in the aerobic step are consistent with expected values for operation on waste activated sludge with low influent solids concentrations (1.9% to 2.9% VS). These results confirm the design model predictions and thus allow extrapolations to higher solids concentrations to be made with confidence.

The high shear aeration device utilized in the aerobic reactor successfully demonstrated sufficient oxygen transfer capacity to achieve and maintain thermophilic temperatures in the aerobic step at short hydraulic retention time and power densities of 0.5 to 1.1 SHP/1000 gal. The device's capability for efficient oxygenation of thickened waste activated sludge was also proved. Oxygen utilization exceeded 65 % of the feed gas flow when the shear device was operated at 32.2 rpm. Furthermore, the data suggested that the efficiency of the high shear device would be enhanced at higher influent sludge concentrations. Solids and temperature profiles indicate that the contents of the aerobic reactor were reasonably well mixed under all conditions.

Preliminary information obtained from an anaerobic digester used temporarily as the second process step indicates that good overall volatile solids destruction, methane purity, and process stability are possible with the dual digestion system.

Data collection on bacteria, virus, and parasite kills demonstrated the ability of the dual digestion system to reduce the levels of pathogens significantly when operated at thermophilic temperatures.

The potential for safe, reliable operation of the dual digestion system with minimum operator attention has been shown.

SECTION 3

RECOMMENDATIONS

The performance of the dual digestion system under operating conditions closer to typical design values should be investigated further. In particular, the long-term operation at a 1-day aerobic, 8-day anaerobic retention time with influent solids concentrations greater than 3% VS is necessary to demonstrate the system's advantages and feasibility completely.

Furthermore, the minimum temperature required to achieve acceptable reductions in pathogens must be identified, and the dual digestion system's ability to consistently maintain this temperature must be demonstrated.

Finally, the source of sludge foaming in the aerobic digester should be identified to establish the chances of its occurrence in future designs. If a high probability of foam occurrence exists, then a low-cost method of foam control should be investigated in a future demonstration program.

SECTION 4

DUAL DIGESTION

PROCESS DESCRIPTION AND DIGESTION TANK DETAILS

The dual digestion system as designed for the Hagerstown, Maryland Wastewater Treatment Plant consists of a short retention time autothermal aerobic digester followed in series by an existing anaerobic digestion step. The primary purpose of this process is to stabilize and reduce pathogens in the thickened waste secondary sludge produced by the air-activated sludge plant through the reduction of volatile matter in the sludge and the production of methane in the second step. The pasteurized residue can then be trucked for safe disposal on land. Figure 1 presents a process flow schematic for the dual digestion system.

The first step of the dual digestion system is a high rate autothermal aerobic digester contained in an insulated, covered, concrete tank of cylindrical geometry. The tank is 11.5 feet in inside diameter with a maximum sludge sidewater depth of 24 feet and a minimum freeboard height of 2 feet. An adjustable external telescoping valve and overflow box maintains the liquid height in the aerobic digester at a depth between 20 and 24 feet. During this demonstration program the liquid level was maintained at 20 feet creating a reactor volume of 16,400 gallons which includes the volume of the drainage well at the bottom of the tank. The aerobic reactor can be maintained at thermophilic temperatures (greater than 45°C) through the conservation of heat generated via biological oxidation of degradable organic matter in the waste sludge and does not require the use of an external heat source.(6, 8) High purity oxygen is introduced into the aerobic reactor by means of static coarse bubble diffusers located at the bottom of the tank. Oxygen transfer from the gas to the liquid phase is enhanced by means of a rotating high shear device which breaks up the oxygen gas bubbles as they rise through the sludge. The use of high purity oxygen, in addition to enhancing the oxygen transfer rate, minimizes the volume of water saturated gas (mainly carbon dioxide and oxygen) which is vented to the atmosphere. This low gas volume minimizes latent and sensible heat losses from the aerobic step and allows the desired operating temperature to be maintained more efficiently. The major mode of temperature control in the first step is the adjustment of the oxygen feed rate and thus the extent of heat producing biological oxidation which occurs. Typically only 5 to 15 percent of the volatile solids content of the sludge need be metabolized to produce the required quantity of heat depending on the desired operating temperature, environmental heat losses and influent sludge characteristics.(5) This last condition was a crucial factor during the Hagerstown program due to persistently low feed solids concentration (<4%TS). This necessitated the occasional use of another mode of temperature control, that of sludge flow adjustment, when feed solids concentrations dropped below critical levels.

By decreasing the sludge flow rate, a reduction in the amount of heat lost with the aerobic sludge effluent compared to that generated by oxidation, was obtained. Despite the undesirability and inconvenience of low sludge concentrations, the ability to control the process was effectively demonstrated.

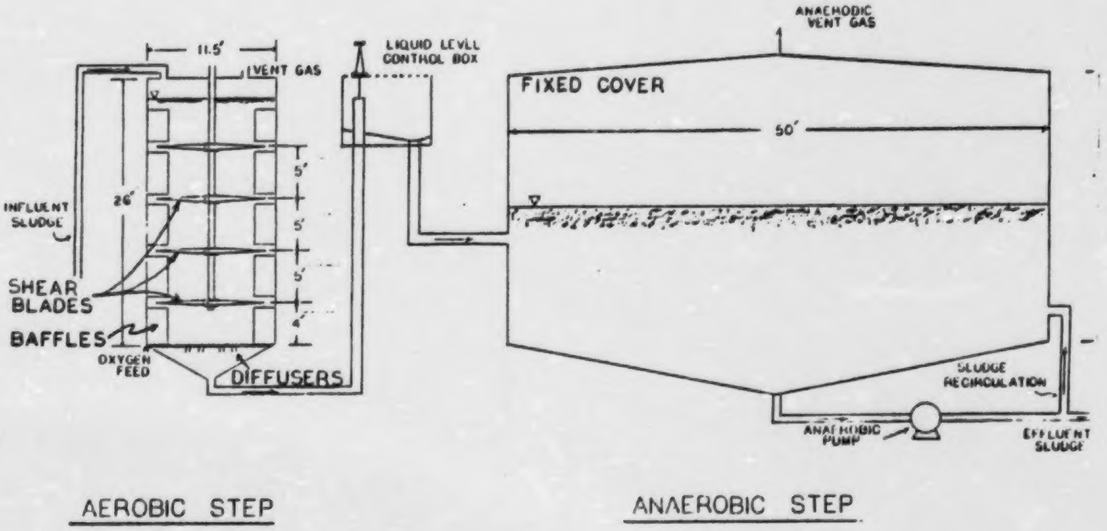
11.5'
VENT GAS
LIQUID LEVEL CONTROL BOX
ANAEROBIC VENT GAS
FIXED COVER
50'
26'
5'
5'
5'
4'
INFLUENT SLUDGE
SHEAR BLADES
BAFFLES
OXYGEN FEED
DIFFUSERS
SLUDGE RECIRCULATION
ANAEROBIC PUMP
EFFLUENT SLUDGE
AEROBIC STEP
ANAEROBIC STEP

Figure 1: Dual Digestion System Process Flow Schematic

Raw sewage entered the Hagerstown Wastewater Treatment facility, was screened and degritted, and then was fed directly to the secondary air-activated sludge tanks. The underflow from the secondary clarifiers was sent either to a gravity thickener or directly to the sludge wet well depending on which flow scheme resulted in a degradable sludge with the highest solids concentration. The sludge was pumped hourly from the wet well to the top of the aerobic digester. Effluent sludge from the aerobic unit flows from the bottom of the reactor, up to the liquid level control box, and then by gravity on to the existing anaerobic unit.

The second step of the dual digestion system consists of a high rate anaerobic digester which receives the heated and partially digested sludge from the autothermal aerobic pretreatment step. The anaerobic reactor completes the stabilization process by further breaking down volatile matter into carbon dioxide and methane gas. Due to the accelerated schedule of this demonstration program the vessels designed as the second step of the dual digestion system were still undergoing rennovation at the time of testing. For purposes of this investigation a spare fifty foot diameter floating cover anaerobic digester with a sidewater depth of 25 feet and a nominal capacity of 396,550 gallons was used. In order to keep anaerobic hydraulic retention times in a reasonable range yet maintain a gas seal over the mid-depth influent sludge pipe, the reactor was operated at slightly more than half its total volume. The reactor cover was dropped to its minimum height and sealed along its outer periphery to prevent gas leakage at this reduced liquid level. A 7.5 horsepower pump was installed for sludge wasting and recirculation mixing.

Figures 2 through 4 are photographs of the major unit processes described in this section.

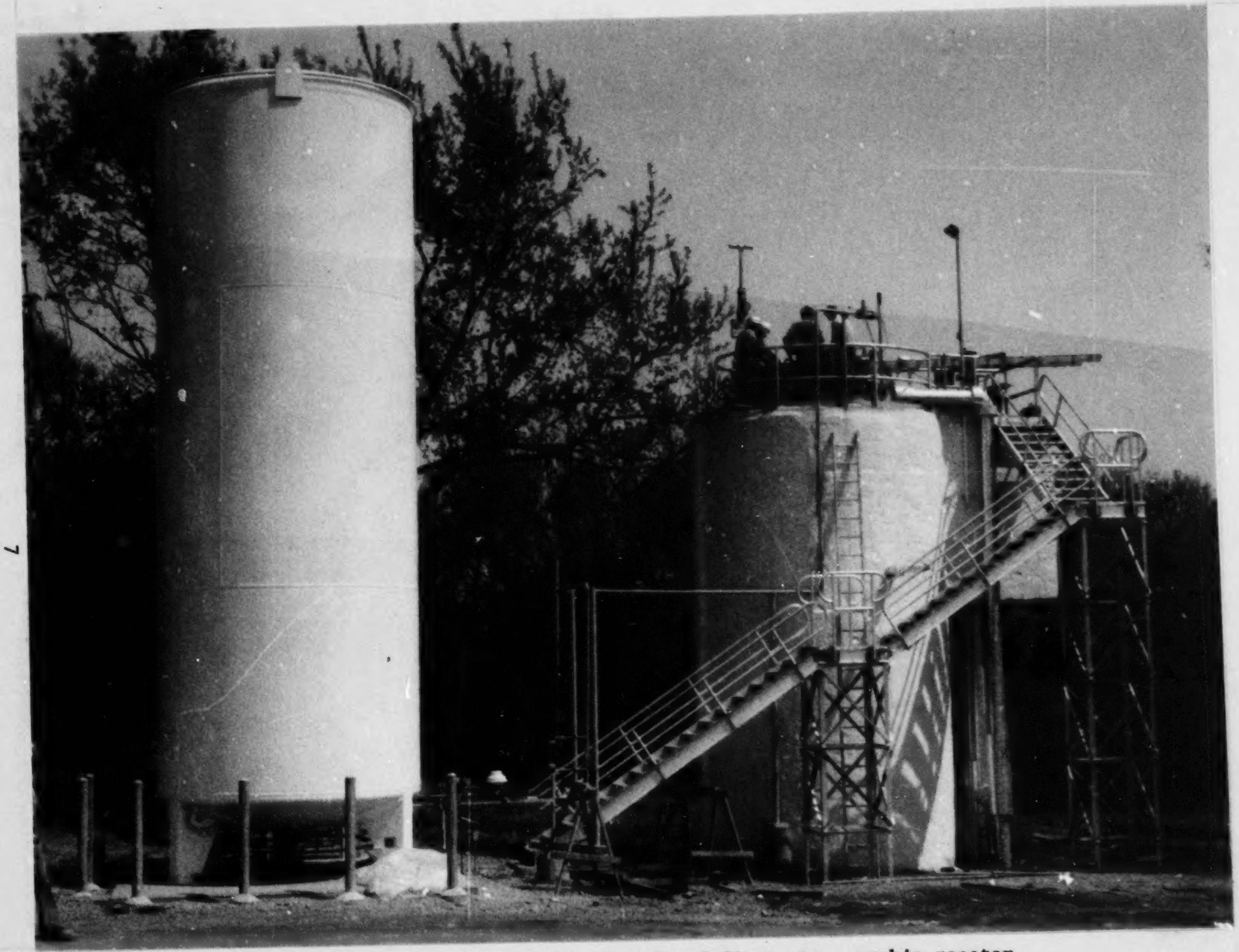

Figure 2. Liquid oxygen storage tank (left) and first step aerobic reactor.

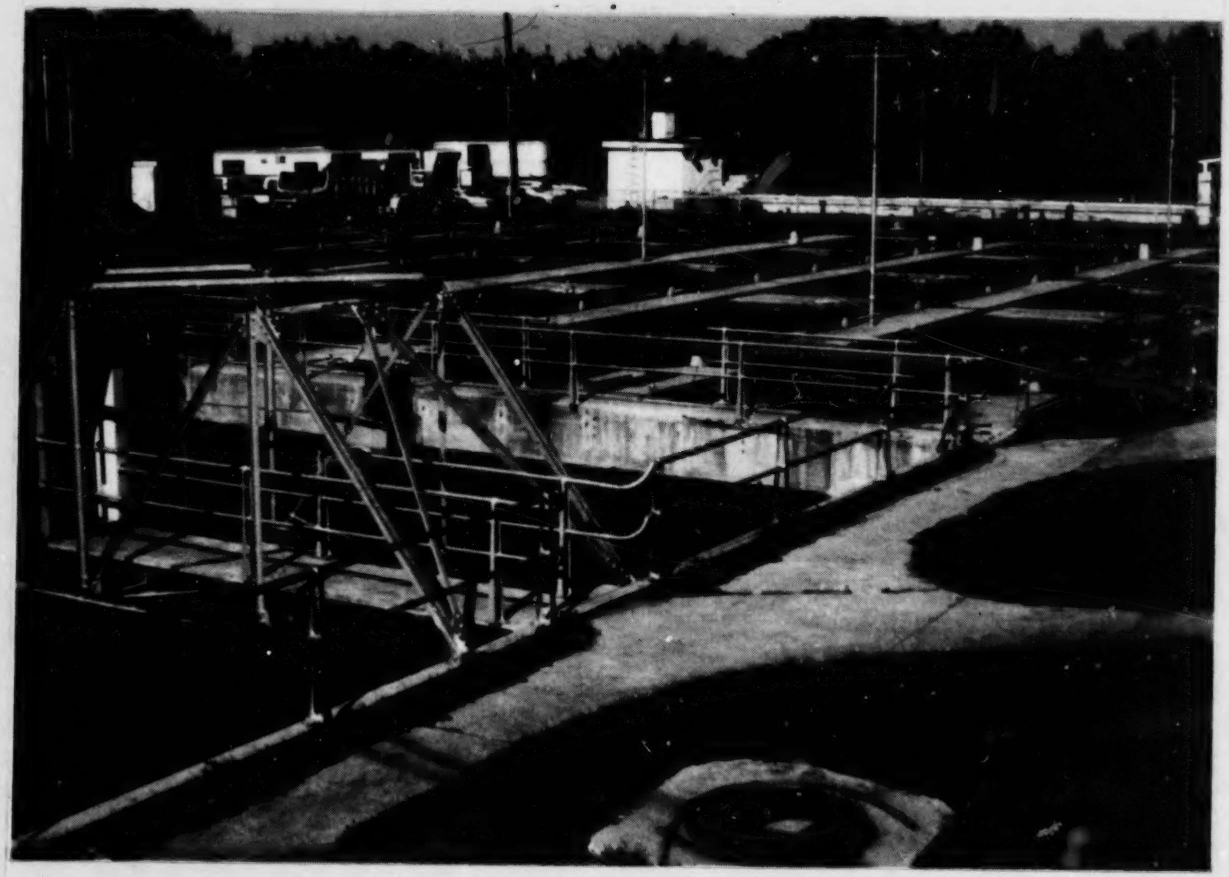

Figure 3. Hagerstown, Maryland Wastewater Treatment Facility.

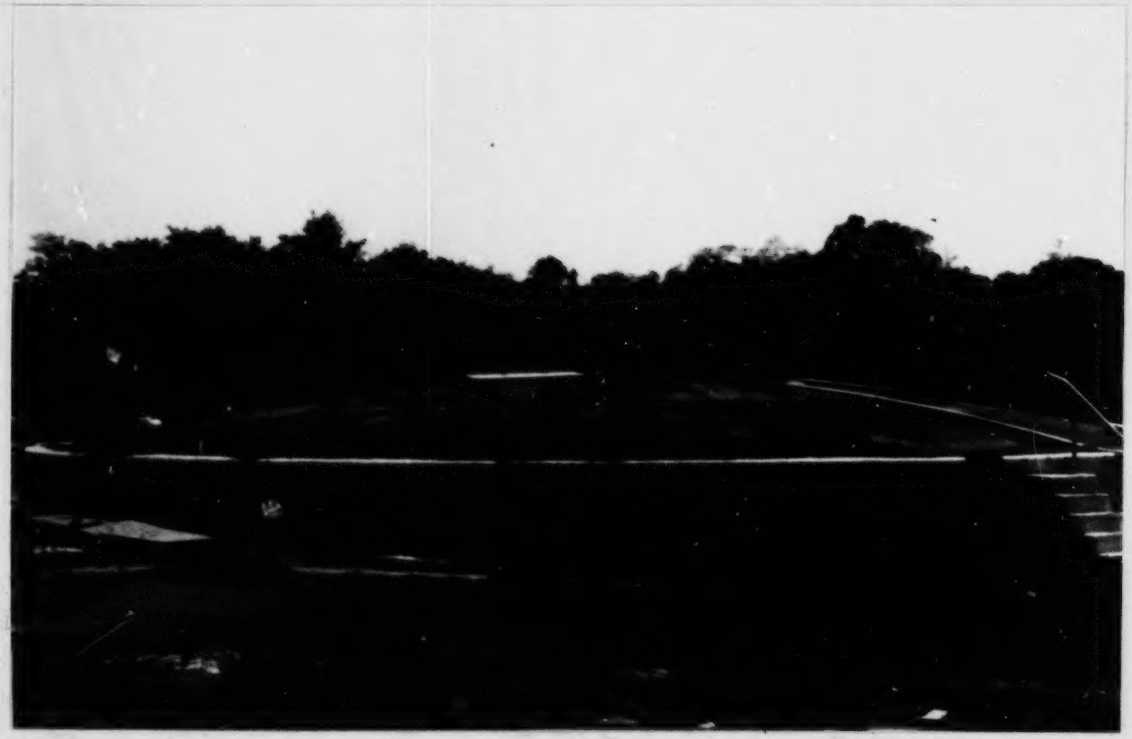

Figure 4. Second step fixed cover anaerobic digester.

SECTION 5

DUAL DIGESTION SYSTEM AND EQUIPMENT DESCRIPTION

HAGERSTOWN WASTEWATER TREATMENT FACILITY

The Hagerstown Wastewater Treatment Plant serves approximately 41,000 persons in the city and its surrounding metropolitan area, including numerous commercial and industrial concerns. Located south of the City, on the banks of Antietam Creek, the facility boasts one of the oldest secondary treatment systems in the United States. Built originally in 1924, an extensive construction program to upgrade the plant is presently underway. Referring to the simplified flow schematic of Figure 5, the nominal 8 MGD plant can be seen to consist of manually cleaned bar screens with 3 inch openings, an aerated grit chamber, grease trap, four diffused air aeration tanks with a total capacity of 2.33 million gallons and a total of five secondary clarifiers (only four in active use) with hydraulic loadings ranging from 400 to 840 gpdpsf at design flow. Effluent disinfection is provided by two chlorine contact chambers having a combined capacity of 225,360 gallons which are equipped with an automated chlorine residual analyzer, controller and recorder.

Before digestion, waste sludge underflow from the secondary clarifiers was normally sent to a pair of covered gravity thickeners which have a total volume of 89,760 gallons and which operate by a fill and draw system. During this study two other modes of thickening were also utilized in an effort to obtain a fresher, more highly concentrated feed sludge. The first mode made use of the spare secondary clarifier as a gravity thickener, while the second mode isolated an aeration tank and secondary clarifier to concentrate solids to desired levels. All three methods provided sludge concentrations in the 2.0% to 3.3% TS range to the wet well from which it was pumped, once an hour, to the dual digestion system. The use of polymer and other thickening agents was investigated and found to enhance solids flocculation and settling but did not substantially improve solids compaction or thickening. The possibilities of renting dewatering equipment or hauling in thick sludge from an outside source were investigated but were rejected as too costly and/or time consuming.

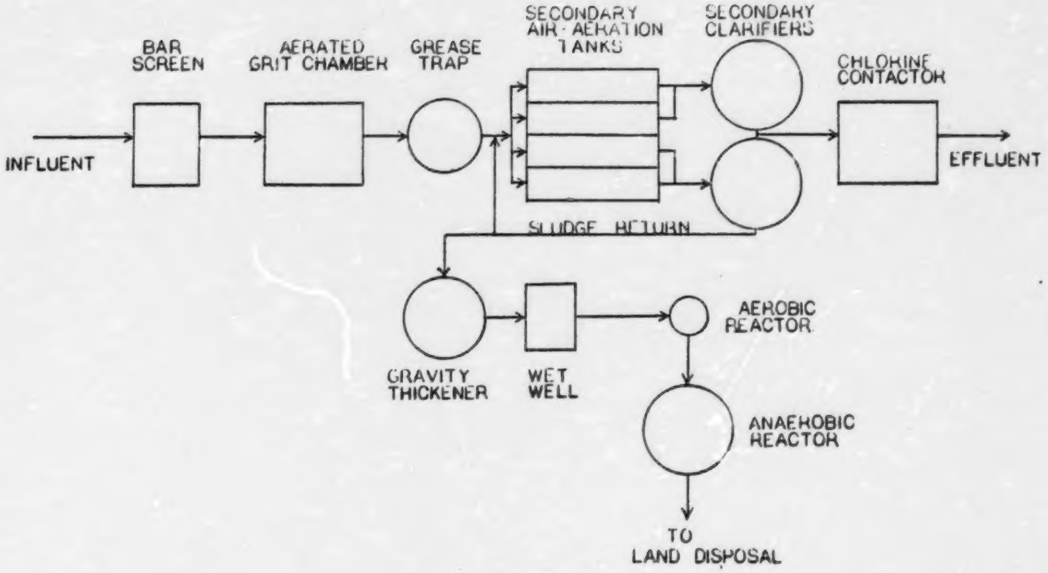
BAR SCREEN
AERATED GRIT CHAMBER
GREASE TRAP
SECONDARY AIR-AERATION TANKS
SECONDARY CLARIFIERS
CHLORINE CONTACTOR
INFLUENT
EFFLUENT
SLUDGE RETURN
GRAVITY THICKENER
WET WELL
AEROBIC REACTOR
ANAEROBIC REACTOR
TO LAND DISPOSAL

Figure 5: Hagerstown Process Flow Schematic

An existing SCRU-PELLER sludge pump, type SLL4 (Chicago Pump), vertically lifted the waste sludge 60 feet from the well to the top of the aerobic digester. A one-hour timer calibrated in approximately 30 second intervals, turned the pump on and off during each feed cycle. The feed period would normally be 2 to 6 minutes out of an hour. Early in the test program it was discovered that the dual digestion system often experienced wide variations in the volume of sludge fed to the reactor each day. This problem is believed to be inherent in this type of sludge pumping system when operating intermittently under fluctuating feed solids concentrations. Since no attractive solution was readily available to stabilize these sludge flow problems the program proceeded under these adverse and inconvenient conditions. The system feed rate, as measured by the daily sludge accumulation in the anaerobic reactor, was used to determine the adjustment of the feed cycle timer required to maintain the desired sludge flowrate.

DUAL DIGESTION SYSTEM

This section describes the major pieces of equipment and instrumentation which are installed at the Hagerstown dual digestion system. The discussion is broken down into three major categories:

- ° Mechanical Equipment
- ° Automatic Valves
- ° Instrumentation

Mechanical Equipment

High Shear Device--

In the first step of the dual digestion system oxygen dissolution is effected by a proprietary high shear mass transfer, aeration device designed and fabricated by Union Carbide Corporation. This unit consists of a vertical shaft made of 5-inch diameter stainless steel, schedule 40 pipe, passing through a liquid seal and extending into the sludge to a depth of 20 feet below the maximum sludge liquid level. Attached to this shaft are four pairs of tapered, conically shaped, stainless steel shear blades of cylindrical cross-section, each pair spanning a distance of 10 feet across the aerobic reactor diameter. These blades are equally spaced at 5-foot intervals along the shaft with the lowest pair of blades located at the bottom end of the shaft. A photograph of the high shear assembly before its insertion into the aerobic reactor is presented as Figure 6. The assembly is driven by a 25 horsepower Westinghouse electric motor and a "Lightnin" mixer gear reducer manufactured by Mixing Equipment Company, Inc. A belt drive unit was placed between the motor and gearbox to provide for speed variations from 24 to 32 rpm during the test program. Figures 7 and 8 present photographs of this equipment on the aerobic reactor deck.

Static Oxygen Diffusers--

High purity oxygen is introduced into the aerobic reactor through eighteen, static, coarse bubble diffusers located at the tank bottom (Figure 9). Each diffuser is composed of a stainless steel orifice covered by a sealing rubber cap located inside of a 6-inch diameter stainless steel shroud. These diffusers have been designed to resist clogging during prolonged operation by providing a gas seal between the diffuser orifice and the sludge.

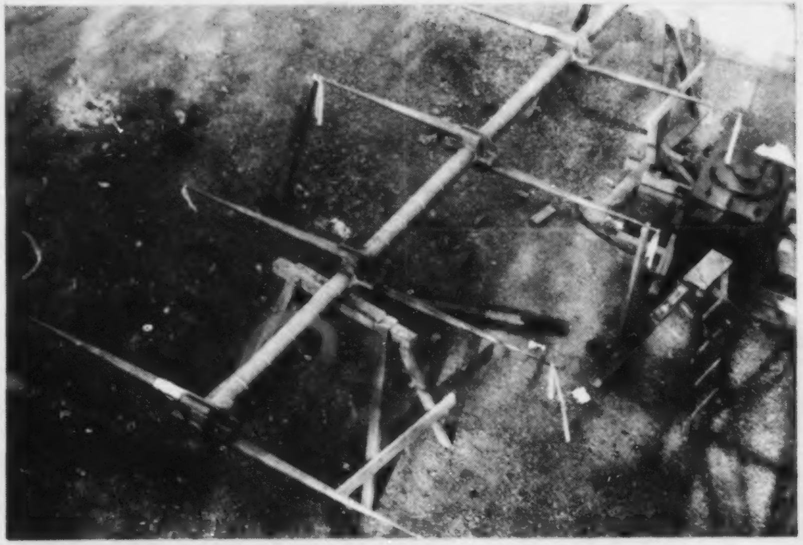

Figure 6. High shear mass transfer device assembly.

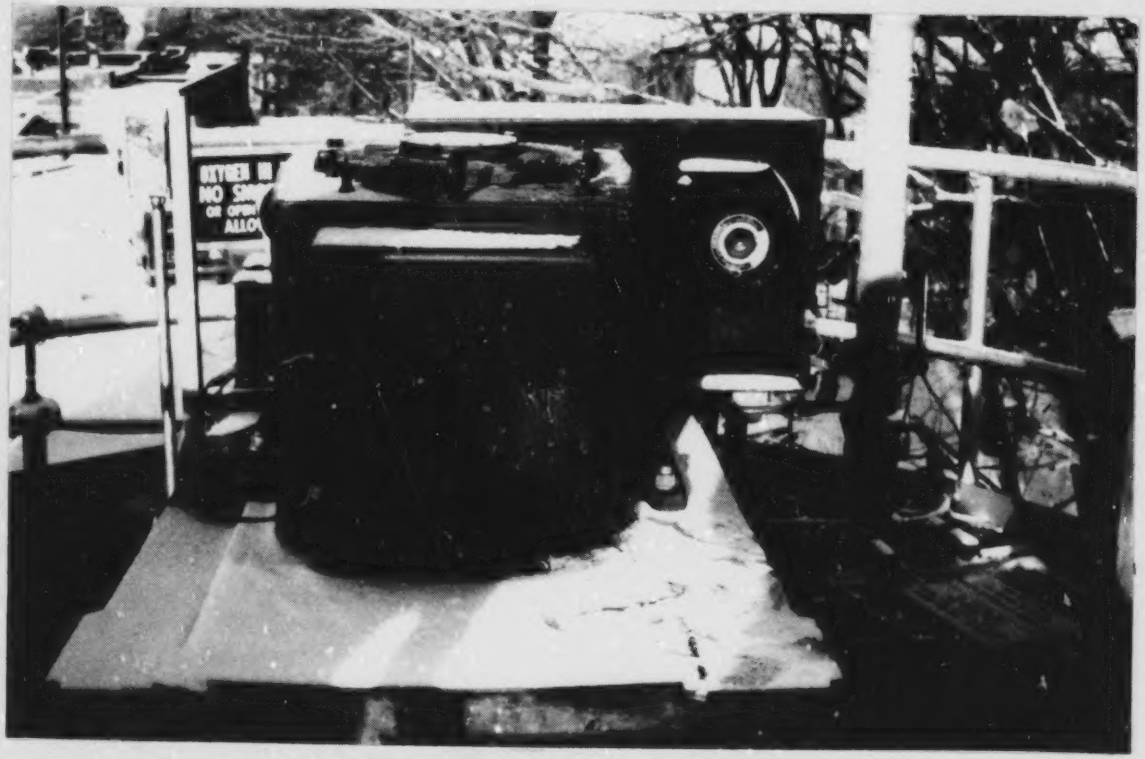
OXYGEN IN
NO SMO
OR OPEN
ALLOW

Figure 7. High shear drive unit showing gearbox and belt drive.

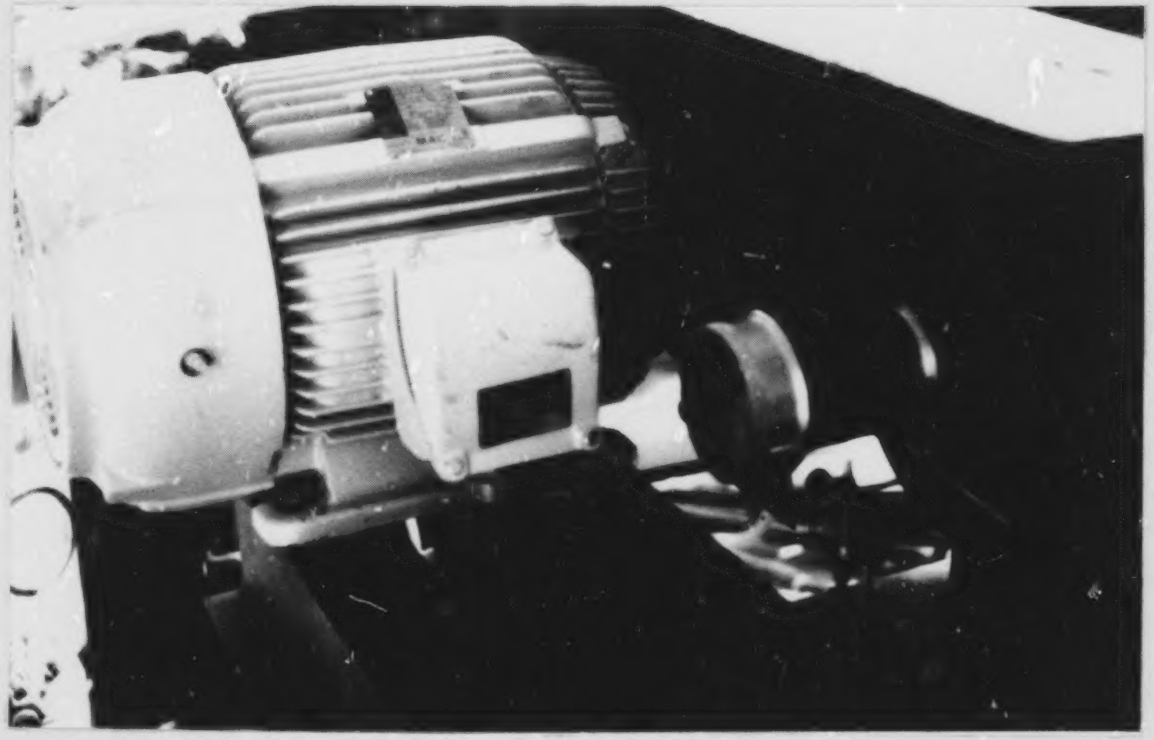

Figure 8. Twenty-five horsepower motor and belt drive unit.

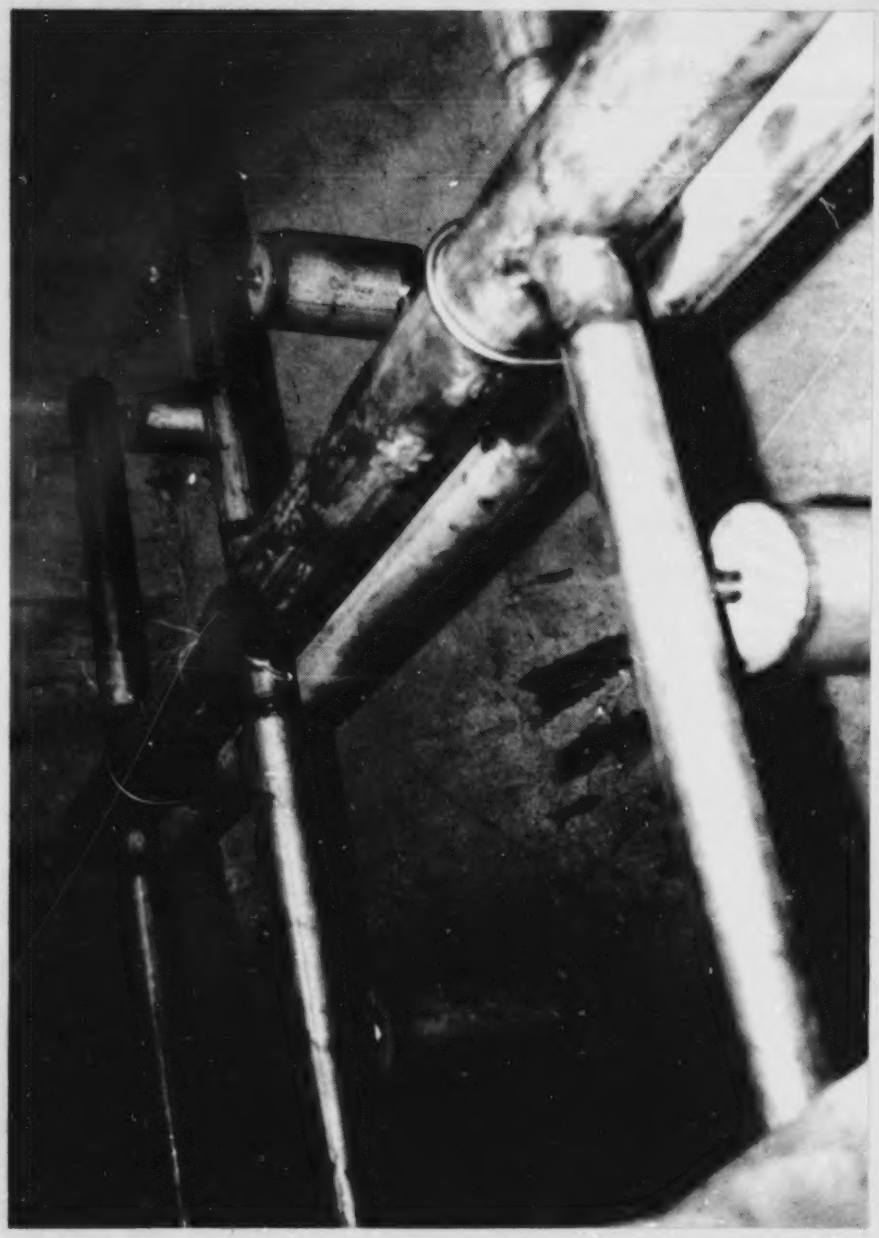

Figure 9. Stationary oxygen diffusers.

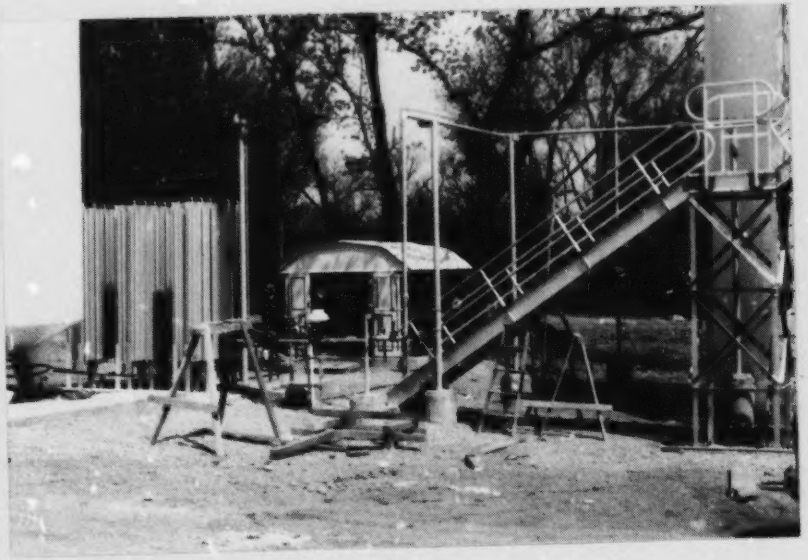

Figure 10. Atmospheric vaporizers and dual digestion control building.

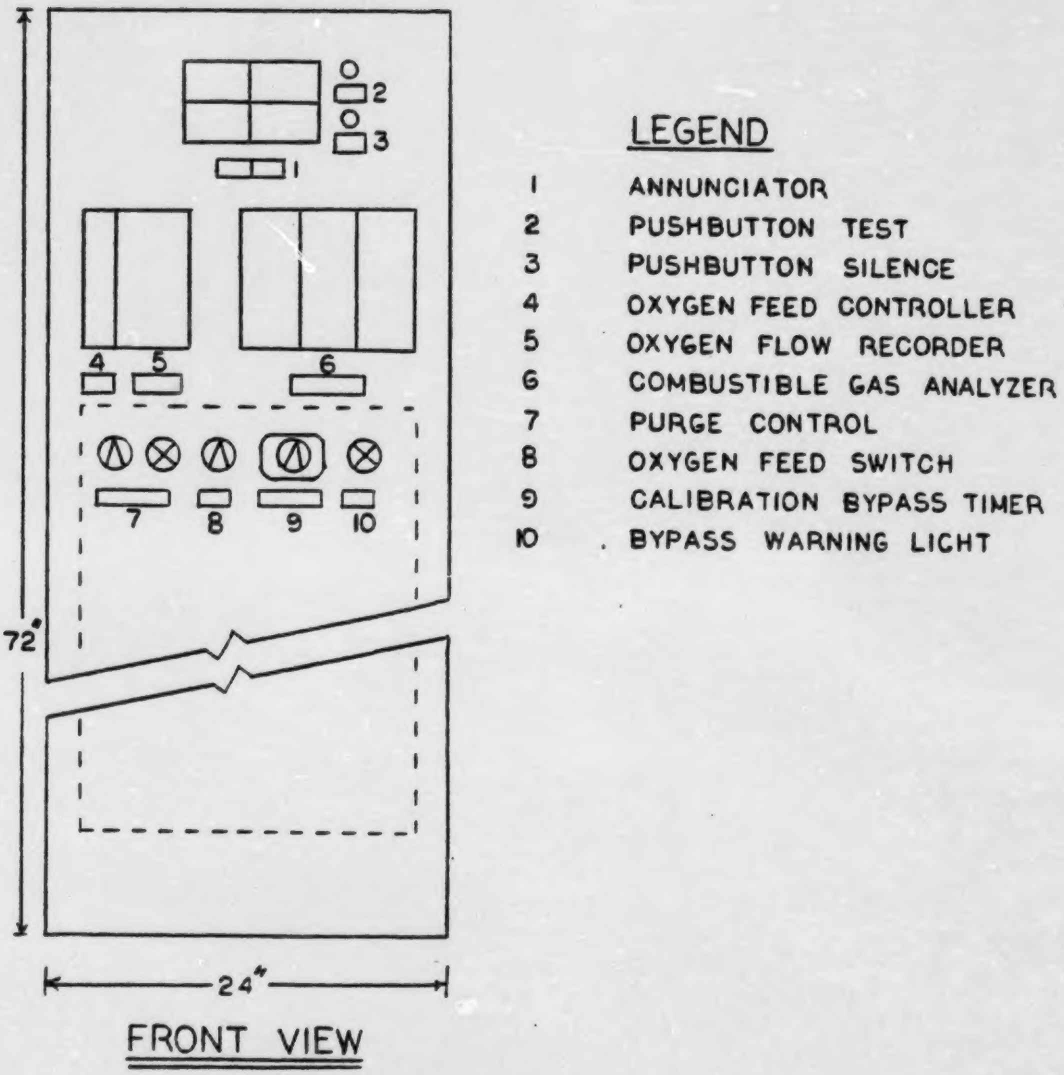
2
3
1
4
5
6
7
8
9
10
72"
24"
FRONT VIEW
LEGEND
1 ANNUNCIATOR
2 PUSHBUTTON TEST
3 PUSHBUTTON SILENCE
4 OXYGEN FEED CONTROLLER
5 OXYGEN FLOW RECORDER
6 COMBUSTIBLE GAS ANALYZER
7 PURGE CONTROL
8 OXYGEN FEED SWITCH
9 CALIBRATION BYPASS TIMER
10 BYPASS WARNING LIGHT

Figure 11: Control Panel Layout

Control Panels--

Located inside of the Dual Digestion Control Building (Figure 10) are panels which contain the electrical switch circuits for the major pieces of mechanical equipment as well as various pieces of control instrumentation. The main control panel contains the combustible gas analyzer, the hand-operated indicator-controller for manual adjustment and reading of the oxygen feed flow, the purge system test circuit and the instrumentation for the oxygen feed flow recorder. In the panel cabinet are the relays and timers associated with the controls on the panel face. The control panel layout is diagrammed for orientation purposes in Figure 11.

Purge Blower--

An air purge blower manufactured by Cincinnati Fan, is located on the top of aerobic reactor (Figure 12). This blower is capable of flushing the step one digester gas space at a rate of 300 CFM in the event of a hydrocarbon alarm situation.

Oxygen Storage--

An 11,000-gallon liquid oxygen storage tank manufactured by Union Carbide's Linde Division provided on-site oxygen supply. Three batteries of atmospheric heat exchangers vaporize the gas for use in the aerobic stage of the dual digestion system (Figure 10).

Anaerobic Digester Waste/Recirculation Pump--

The sludge liquid level in the anaerobic digester was maintained through the use of a Gorman Rupp trash pump (model 13C2-B) driven by a 7.5 horsepower electric motor. This pump served the dual purpose of sludge wasting and recirculation mixing in the anaerobic reactor.

Automatic Valves

Oxygen Feed Control Valve--

The oxygen feed control valve is a 1-inch pneumatically controlled split-body globe valve. The diaphragm motor of the valve receives a 3 to 15 psig signal from the manual control station located in the main control panel which adjusts the valve opening and regulates oxygen flow.

Purge Air Valve--

The purge air valve is a 6-inch pneumatically controlled butterfly valve. The valve operates in conjunction with the purge air blower and is activated by a signal from the combustible gas detection system.

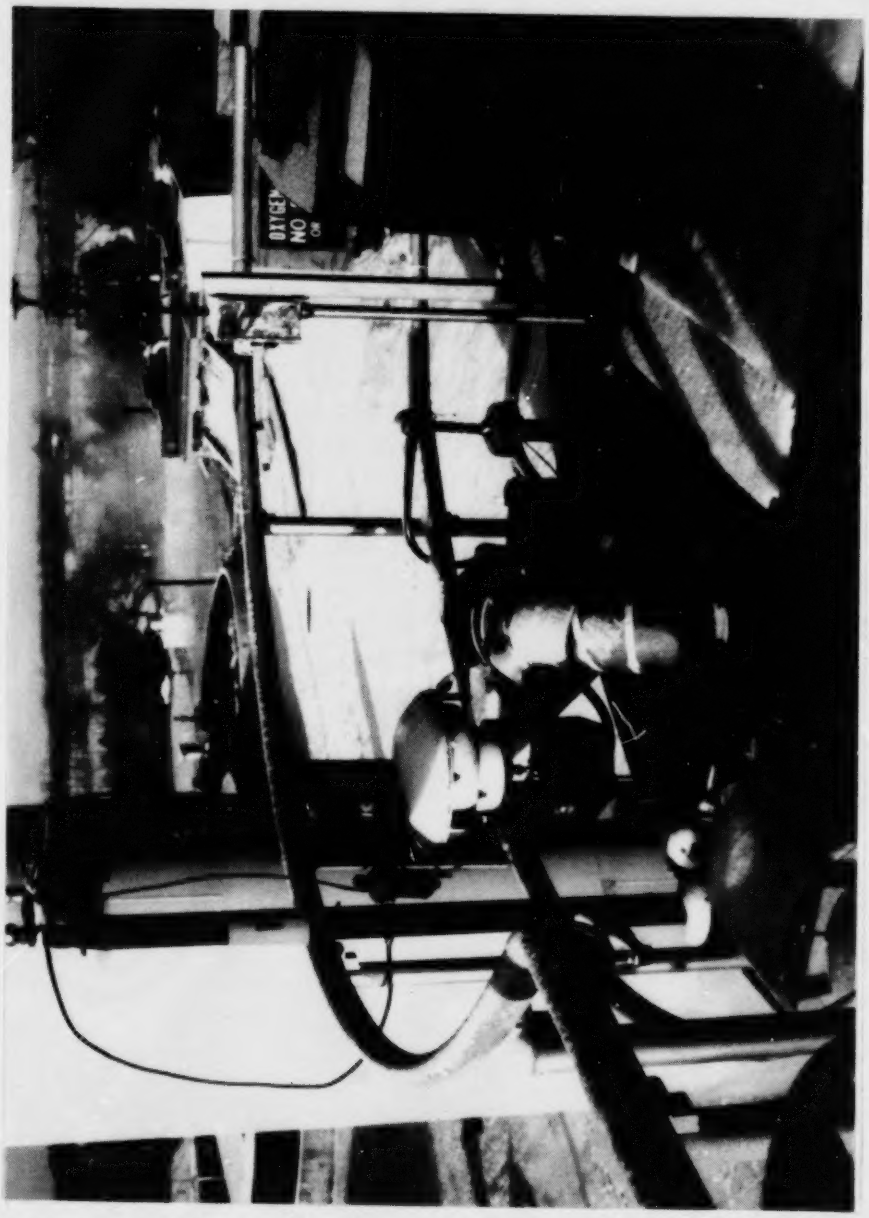

Figure 12. View of aerobic reactor deck - purge blower and valve.

Aerobic Digester Relief Valve--

The aerobic digester relief valve is a 6-inch Shand and Jurs open vent type breather valve. The valve is of anodized aluminum construction and is designed to provide both pressure and vacuum relief with vapor tight seating within the operating range. The valve has a pressure relief setting of 8 inches of water column pressure and a vacuum relief setting of -4 inches water column pressure (Figure 13).

Instrumentation

Oxygen Feed Controller--

The manual oxygen feed controller is located in the main control panel. The controller is direct acting: an increasing input signal causes the controller output to increase, tending to open the oxygen feed valve wider. The output is a 3-15 psig pneumatic signal which controls the position of the automatic oxygen feed control valve. The unit consists of a thumbwheel and scale such that at a setting of zero the valve is fully closed while a setting of 100 indicates a fully open valve.

Oxygen and Vent Gas Flow Measurement--

The oxygen feed flow to the aerobic digester is actually measured by two instruments. The first, a Fisher and Porter rotameter, is rated for a maximum flow of 54.4 CFM of air. This unit is permanently mounted in the oxygen feed line downstream of the automatic feed valve. The second means of flow measurement is an Eastech flow transmitter and totalizer temporarily mounted in the oxygen feed line on the reactor deck. This transmitter features a dual thermal sensor mounted on a fixed-flow element. The measurement of flow is made by counting the rate at which vortices are shed from the fixed-flow element located in the line. This measurement is then translated into an electrical signal and sent to the flow recorder located in the main control panel. Local pressure and temperature indicators mounted in the feed and vent piping allow for correction of gas flow measurements to standard conditions.

Substantial difficulties were encountered in finding a device which would accurately and consistently measure the low pressure, warm and humid vent gas flow from the aerobic digester. A low speed, vane type anemometer (made by Davis Instrument Manufacturing Company) was selected for its simplicity and ease of maintenance. Multiple in-line readings were taken for each test with the results averaged and corrected for temperature and pressure.

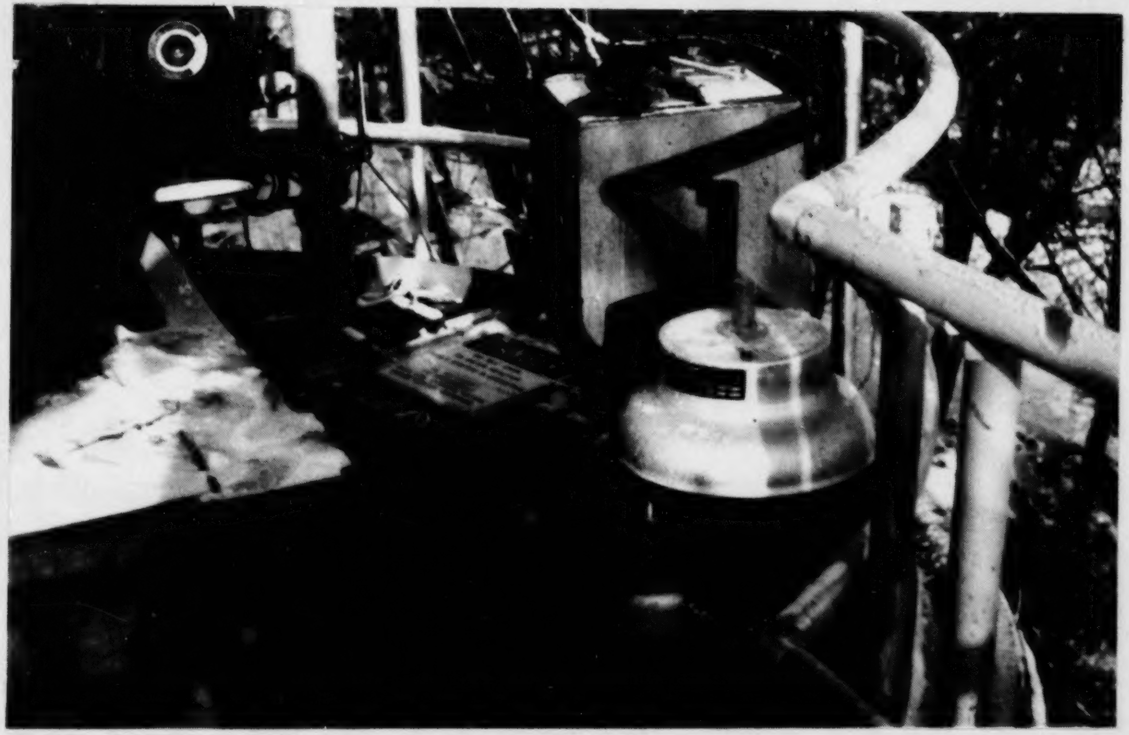

Figure 13. View of aerobic reactor deck - lower explosion limit sampler and relief valve.

Combustible Gas Detection System--

A Mine Safety Appliance Company (MSA) combustible gas detection system is utilized to measure any possible combustible gas concentration in the aerobic reactor gas space. The detector element for this system is located in an enclosed box on the aerobic reactor deck (Figure 13) which continually samples the hydrocarbon concentration in the reactor gas space. This measurement is converted to an electrical signal to the combustible gas analyzer located in the main control panel. The MSA system provides two alarm levels, one set at 25 percent of L.E.L. (lower explosive limit) and the other at 50 percent of L.E.L. Alarm signals are annunciated on the main control panel and are also used to initiate automatic responses to these conditions, if they should occur.

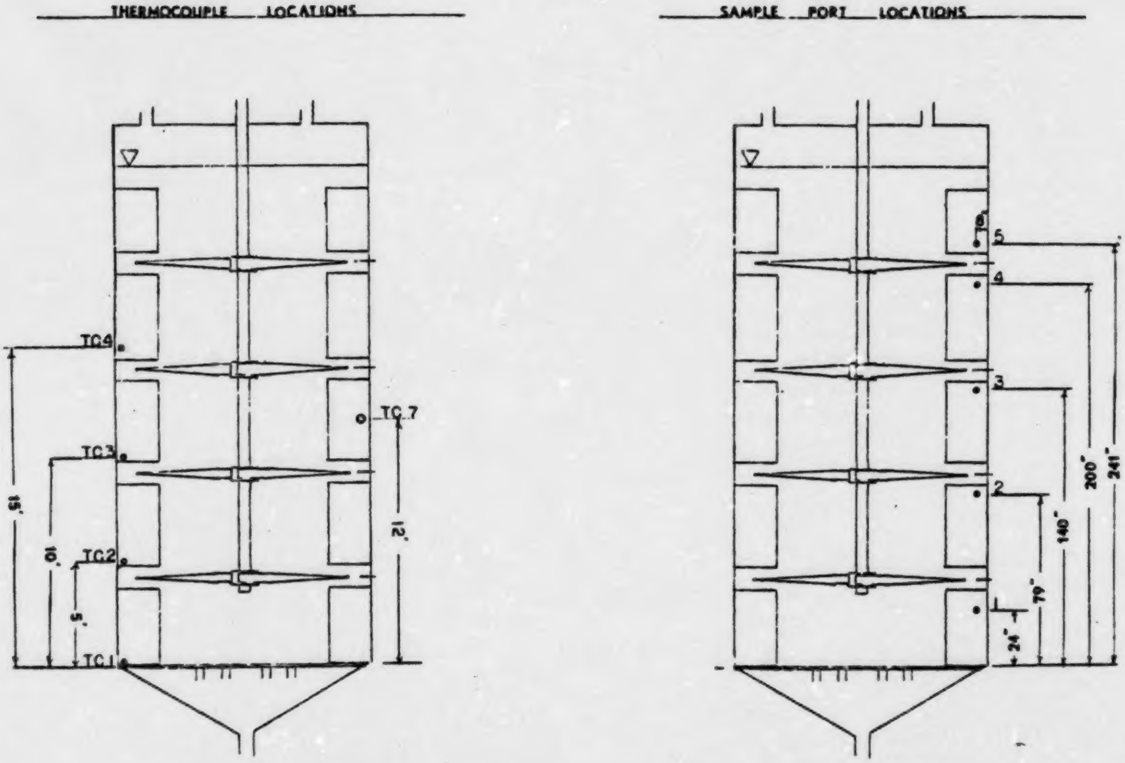
THERMOCOUPLE LOCATIONS
TC4
TC 7
TC3
TC2
TC1
15'
10'
5'
12'
SAMPLE PORT LOCATIONS
6
5
4
3
2
1
24"
79"
140"
200"
241"

Figure 14: Aerobic reactor - thermocouple and sample port location.

Temperature Measurement-

All temperature measurements were made with copper-constantan thermocouples (type T) inserted into the aerobic reactor (Figure 14) and into the various process lines. Permanent thermocouples in the sludge feed line and aerobic reactor were manufactured by CONAX. The electromotive force generated by the thermocouples hot junction is converted into a temperature readout by a Minneapolis Honeywell Brown multipoint temperature recorder located in the Dual Digestion Control Building (Figure 15).

Vent Purities--

Gas was periodically withdrawn from the aerobic reactor vent line via a Thomas Industries compressor located in the gas sample cabinet in the Dual Digestion Control Building (Figure 15). The vent gas sample passes through a pair of cooling coils, through a water trap and through a filter which has a small drain tap to remove excess moisture. Finally the vent gas sample passes through a small 0-1.5 CFM rotameter to a paramagnetic oxygen analyzer. This SERVOMEX analyzer (manufactured by Taylor Sybron Corporation) offers two scales of oxygen purity, 0-25% and 0-100%, with the latter scale being used during this test program. Cylinder gases of known composition were provided for daily calibration of the analyzers.

The oxygen content of the anaerobic digester off gas was measured in a manner similar to that of the aerobic vent gas. However, in addition to oxygen, the methane and carbon dioxide content of the anaerobic gas were also measured on a daily basis by a pair of infrared emission analyzers, made by Infrared Industries, Inc.

Power and RPM Measurement--

The motor power draw of the high shear mass transfer device was measured by a permanently installed General Electric 0-50 KW wattmeter in the Dual Digestion Control Building. In addition, a temporary recording wattmeter (Esterline Angus) was installed to provide a long-term record of motor power draw.

A proximity switch installed on the high shear shaft provided a count of mixer rotation which read out on a voltmeter located in the control building. From this count the high shear rotational speed could be determined with the aid of a stopwatch.

Anaerobic Digester Sludge Level--

A gas bubbler liquid level measuring system was installed in the second step of the dual digestion system. Cylinder nitrogen was slowly fed through a tube to the bottom of the anaerobic digester and the pressure measured by an in-line gage. This pressure reading was then converted to liquid head in order to determine the depth of sludge in the reactor. The difference in sludge level on a day-to-day basis provided an accurate measurement of the total sludge volume fed to the dual digestion system.

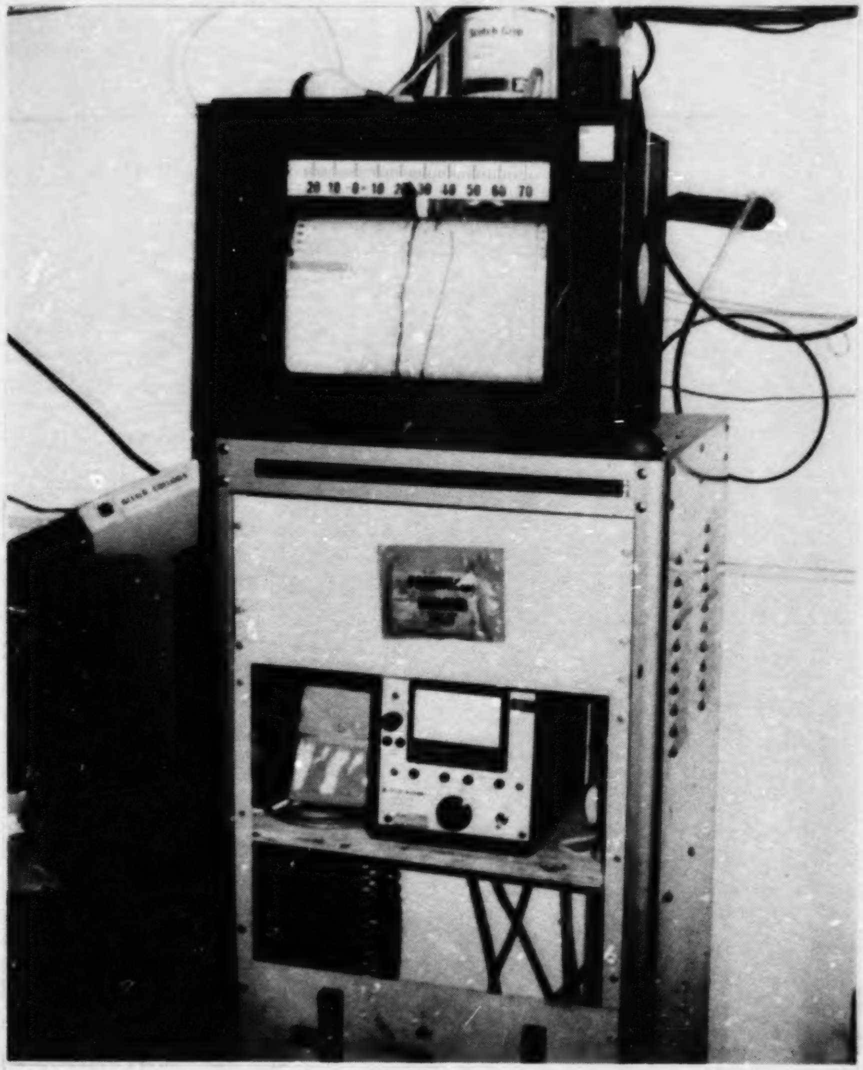
20 10 0 10 20 30 40 50 60 70

Figure 15: Brown multipoint recorder (top) and vent gas analyzer.

Sludge Samplers--

Daily composite samples of the aerobic feed, mixed liquor and effluent were used to determine solids removals across the first step reactor. The feed sludge sample location was the wet well where a Sigma Motors composite sampler withdrew an aliquot of liquid every hour. Aerobic effluent samples were pumped from the adjustable standpipe in the overflow box of the first step reactor by a Masterflex peristaltic pump on a one hour cycle timer (Figure 16). Similarly mixed liquor samples were pumped from sample ports located inside the aerobic reactor (Figures 14 and 17). Totalized samples were removed for analysis at approximately 8:30 am each morning.

Anaerobic sludge samples were taken on a grab basis during daily sludge wasting from the second step.

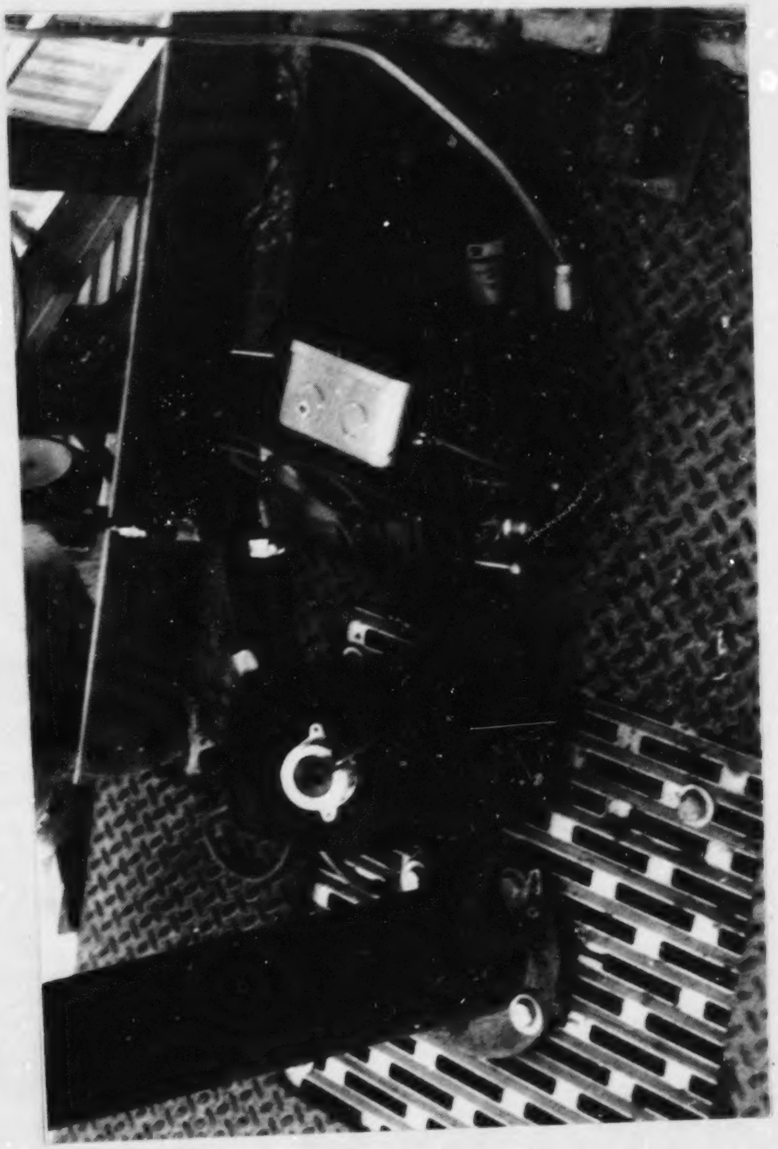

Figure 16. Aerobic effluent sampler.

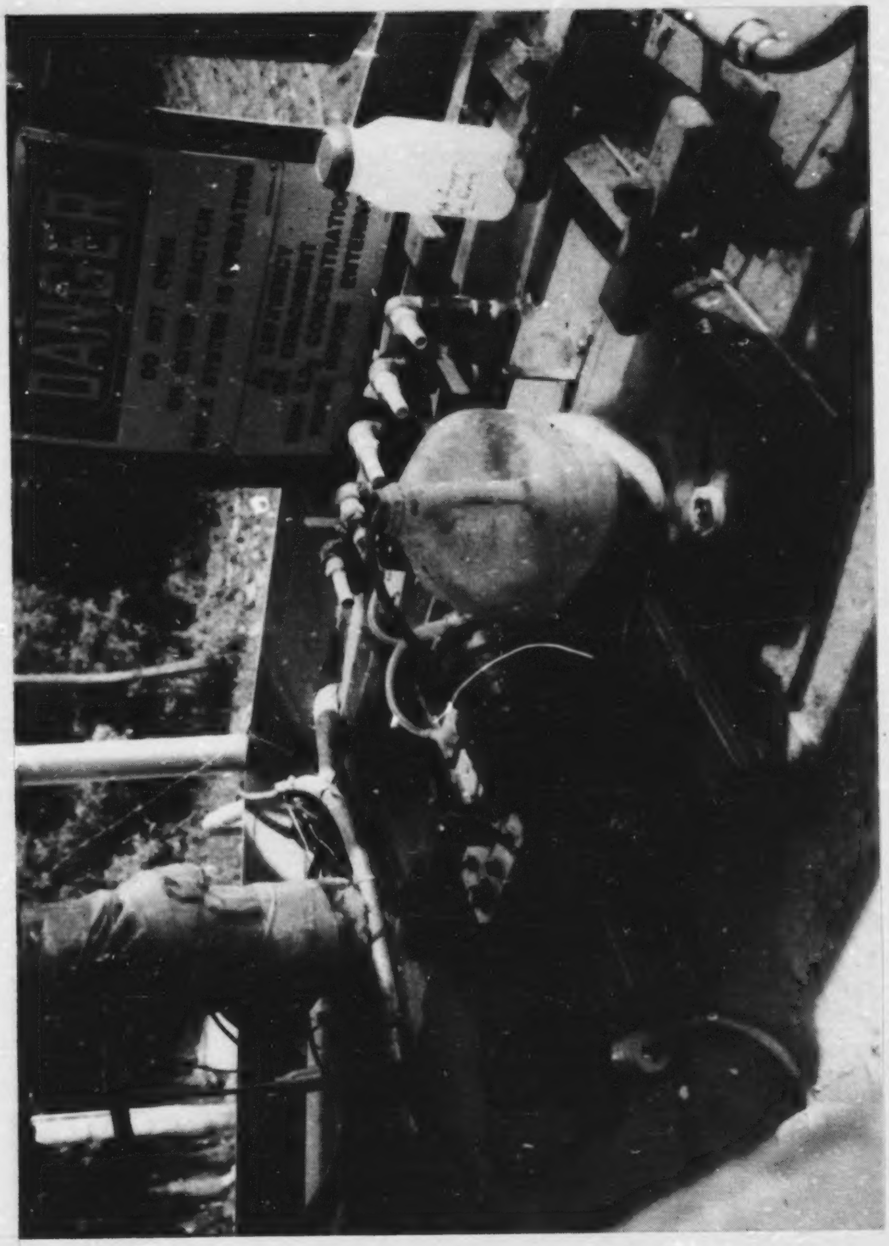

Figure 17. Aerobic mixed liquor sampler.

SECTION 6

PROCESS OBSERVATIONS

ACHIEVEMENT OF THERMOPHILIC TEMPERATURES

The main goal of this test program was to demonstrate that thermophilic temperatures could be autothermally achieved in the aerobic step at short retention times and modest volatile solids reduction. This task was accomplished in a relatively short period of time as discussed below.

The Hagerstown Dual Digestion Demonstration Plant was started on June 11, 1980 with the aerobic reactor being filled to the 20-foot level (approximately 16,400 gallons) with thickened (3.4%) secondary sludge. Beginning June 13, secondary sludge feed was initiated at a rate sufficient to main- tain a one-day aerobic retention time. As can be seen from Figure 18, by the end of the seventh day of operation the aerobic digester temperature had risen to the thermophilic region (greater than 45°C). By the ninth day (June 21) the temperature had reached 55°C without the aid of external heating. At that point the oxygen feed rate was lowered to stabilize the sludge temperature and increase oxygen utilization.

Measurements of process variables such as reactor temperature, gas feed flow, vent oxygen purity and mixer rpm were measured at least three times a day (morning, afternoon and evening). The average of these three readings is reported as a daily average with the data being further reduced to weekly (seven day) and test phase average results. The following table summarizes the operating conditions which prevailed during the start-up phase 06-11-80 to 06-19-80:

TABLE 1. START-UP PROCESS CONDITIONS (6/11 - 6/19/80)

Parameter	Start-up Phase Average	Range
Aerobic Retention Time, days	1.12	1.0 - 3.1
Feed Temperature, °C	18.3	16.5 - 20.0
Solids Concentration, %		
TS	3.44	3.23 - 3.58
VS	2.75	2.59 - 2.89
Oxygen Flow Rate, CFM-NTP	21.5	16.0 - 25.0

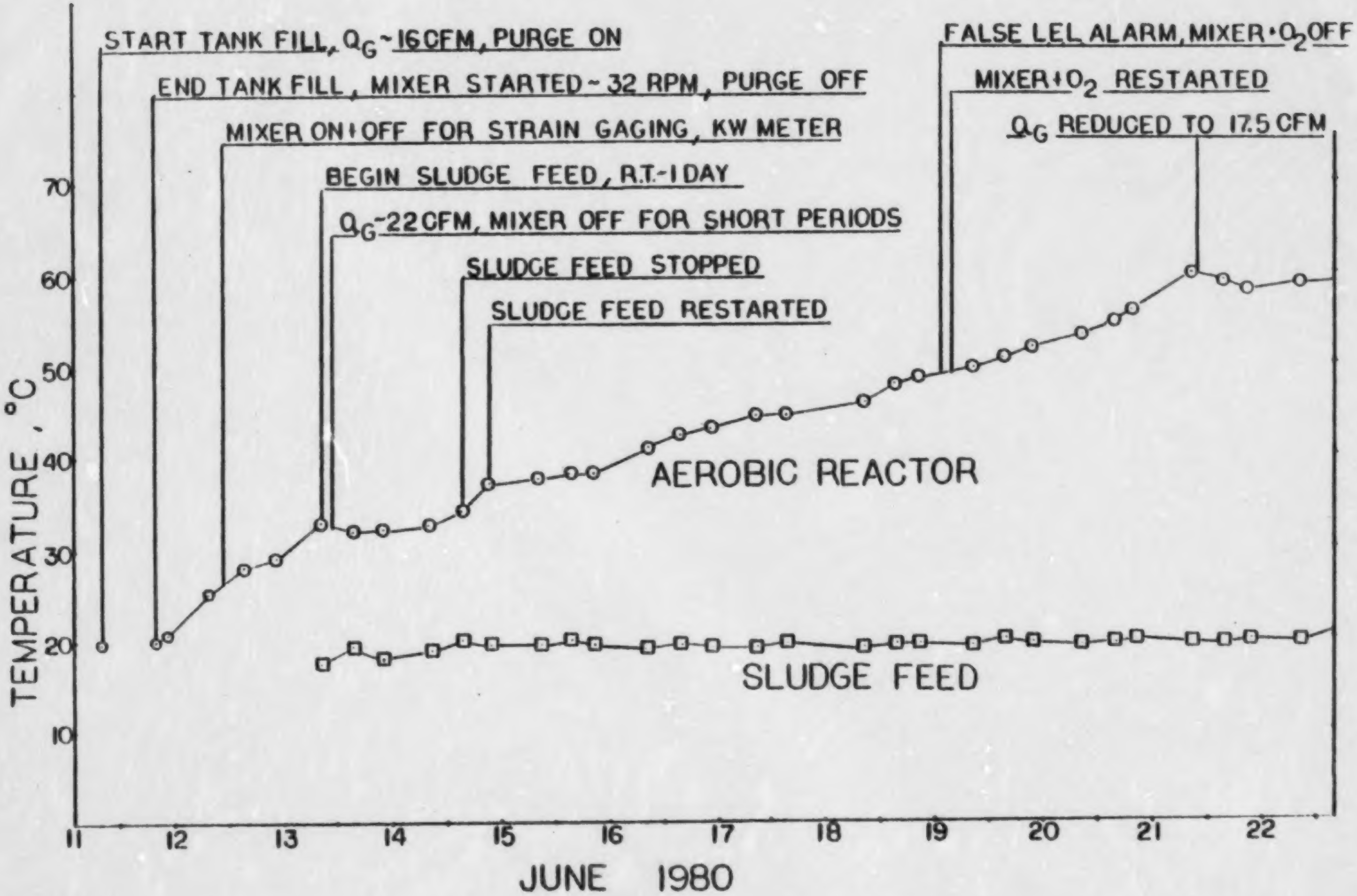

Figure 18. Process start-up.

TABLE 2. HAGERSTOWN DUAL DIGESTION SYSTEM - WEEKLY AVERAGE DATA

PARAMETER		Week of 06-11 START-UP	06-16	06-23	06-30	07-07	07-14	07-21	07-28	08-04	08-11	08-18	08-25	09-01	09-08	09-15	09-22	09-29	10-06	10-13	10-20	10-27
Retention Time, Days																						
Aerobic		3.31	1.02	1.04	1.23	1.22	1.08	0.87	1.19	0.93	1.70	1.67	1.39	0.98	0.96	1.35	1.63	1.62	1.34	1.08	2.23	2.25
Anaerobic		—	—	—	10.67	10.39	9.44	9.60	18.18	14.69	26.67	26.00	24.89	15.44	15.16	22.58	24.97	23.81	22.29	16.72	33.72	33.75
Temperature, °C																						
Feed		19.1	19.5	22.1	23.1	23.6	24.9	28.2	25.7	26.8	25.5	24.8	25.1	25.7	26.1	25.5	24.8	22.8	21.6	20.9	19.6	17.3
Aerobic		30.5	50.9	56.7	53.7	52.6	52.1	51.3	53.8	46.5	45.8	47.2	50.3	47.6	47.8	51.5	47.0	49.4	57.3	51.3	52.5	52.3
Anaerobic		—	—	38.3	40.8	41.6	43.3	44.2	43.4	43.1	41.9	41.0	41.1	42.4	42.2	42.8	42.3	41.4	40.3	41.7	41.0	39.0
Ambient		18.8	20.0	25.2	25.9	25.1	28.8	26.5	27.2	27.4	24.0	22.3	26.0	25.5	22.0	23.5	20.1	14.7	13.7	13.6	10.8	7.5
Aerobic Vent		26.5	42.2	46.4	44.8	44.1	43.5	43.7	46.7	41.2	41.6	42.3	41.7	41.6	38.7	42.1	—	—	—	—	—	—
Solids, %																						
Feed	TS	3.40	3.54	3.57	3.43	3.34	3.36	3.12	3.26	2.78	2.50	2.28	3.03	2.75	3.32	3.02	2.77	2.76	3.09	3.39	2.88	2.81
	VS	2.74	2.81	2.87	2.73	2.59	2.53	2.43	2.36	2.19	2.00	1.86	2.48	2.27	2.73	2.47	2.24	2.22	2.47	2.71	2.23	2.26
Reactor	TS	2.35	2.68	3.18	2.69	2.75	2.80	2.51	2.36	2.49	2.00	1.83	2.19	2.11	2.51	2.63	1.97	—	2.13	—	2.38	2.16
	VS	1.87	2.09	2.56	2.17	2.25	2.08	1.92	1.79	1.94	1.57	1.49	1.75	1.72	2.04	2.25	1.61	—	1.69	—	1.71	1.76
Effluent	TS	2.04	2.78	2.84	2.69	2.82	2.81	2.56	2.29	2.49	1.82	1.80	1.94	2.08	2.38	2.15	2.01	1.64	2.77	2.77	2.16	2.10
	VS	1.61	2.16	2.17	2.08	2.13	2.03	1.93	1.65	1.86	1.39	1.42	1.53	1.66	1.68	1.83	1.70	1.34	1.22	2.16	1.64	1.62
Anaerobic	TS	—	2.28	2.22	2.14	2.37	2.46	2.49	2.14	2.08	1.90	1.81	1.54	1.51	1.54	1.62	1.97	1.67	1.65	1.78	2.08	1.87
	VS	—	1.70	1.72	1.57	1.73	1.72	1.84	1.53	1.48	1.30	1.27	1.06	1.08	1.26	1.20	1.34	1.21	1.22	1.28	1.44	1.34
Volatile Solids Removal, %																						
Aerobic		41.2	23.1	24.4	23.8	17.8	19.8	20.6	35.5	15.1	30.5	23.7	38.3	26.9	38.5	21.8	24.1	30.6	30.6	20.3	26.5	28.3
Overall		—	39.5	40.1	42.5	33.2	32.0	24.3	40.2	32.4	35.0	31.7	57.3	52.4	53.8	51.4	40.2	45.5	50.6	52.8	34.5	40.7
pH																						
Feed		5.78	6.02	6.02	5.94	6.36	5.79	5.47	5.93	6.00	6.00	6.10	6.10	6.18	6.00	6.02	5.97	6.04	6.02	5.96	6.03	6.09
Aerobic		6.52	7.05	7.13	7.13	7.03	6.84	6.96	7.23	7.00	7.10	7.30	7.40	7.00	6.78	7.02	7.07	6.99	7.16	7.03	[illegible]	7.21
Anaerobic		—	7.25	7.32	7.36	7.36	7.16	6.90	7.06	7.40	7.50	7.40	7.60	7.38	7.38	7.40	7.46	7.26	7.25	7.24	7.27	7.23
Gas Purities, %																						
Aerobic Vent O		75.1	63.5	49.8	62.8	61.9	44.4	61.2	69.2	80.2	86.6	82.4	67.9	68.4	58.4	73.9	80.2	82.1	73.2	60.4	77.1	69.3
Anaerobic Vent CH_4		—	—	50.0	54.3	51.2	47.1	37.7	48.8	60.4	51.9	47.7	44.8	44.6	49.0	50.7	—	—	—	—	—	—
Anaerobic Vent CO_2		—	—	—	—	—	45.7	45.3	38.2	29.2	29.7	27.0	26.6	30.4	31.5	29.5	—	—	—	—	—	—
Anaerobic Vent O_2		—	—	1.17	1.83	1.95	1.24	1.66	1.37	0.55	1.36	1.95	3.31	1.48	1.42	1.35	—	—	—	—	—	—
Oxygen Feed Flow																						
CFM-NTP		22.6	19.9	14.5	17.5	16.9	15.9	18.9	18.0	27.3	27.8	22.1	19.8	17.0	19.8	23.8	18.4	21.1*	17.4	17.4	17.4	13.6
High Shear																						
LRP, KW		15.1	18.0	17.40	19.00	17.80	19.80	20.10	19.40	9.58	10.54	11.26	12.17	13.56	16.60	15.60	17.36	17.61	18.37	18.44	18.06	17.70
RPM		32.2	32.1	32.1	32.0	32.1	32.1	32.2	32.1	24.2	24.2/28.7	28.7	28.6	28.4	28.5/32	32.3	32.2	32.2	32.1	32.2	32.3	32.3

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*O_2 data from 09-29 to 10-27 expressed in ACFM.

"Detention times are calculated from known liquid volumes in the digesters and the sludge flow rate that was measured once each day. Weekly averages are presented in the table."

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MAINTENANCE OF THERMOPHILIC TEMPERATURES

A second major goal of the demonstration program was to maintain aerobic temperatures in the 45° to 60°C range while operating at short retention times (1 to 2 days). That the test program has been successful in this regard is illustrated by Figure 19 and Table 2 which respectively present daily and weekly averages of Hagerstown results over the course of some 20 weeks of operation. These results have been achieved despite wide variations in sludge feed flow and influent solids concentration well below those desired for typical dual digestion designs. When feed solids concentrations dropped the hydraulic retention time of the aerobic step was increased in order to compensate. Also note that the range on certain process parameters reflects different operating conditions imposed on the system during portions of the test program.

The following table (table 3) summarizes test results for the test period 06-23-80 to 11-02-80.

TABLE 3. TEST PROGRAM PROCESS CONDITIONS (6/23 - 11/02/80)

Parameter	Test Program Phase Average	Range
Aerobic Retention Time, days	1.38	0.6 - 8.8
Anaerobic Retention Time, days	19.9	9.6 - 34.0
Temperature, °C		
Feed	23.8	16.8 - 28.3
Aerobic	50.5	42.3 - 60.0
Anaerobic	41.7	37.5 - 47.0
Ambient	21.5	5.0 - 40.0
Influent Solids Concentration, %		
TS	3.02	1.50 - 4.11
VS	2.41	1.23 - 3.33
Volatile Solids Removal, %		
Aerobic	27.2	15 - 51
Overall	41.6	24 - 57
Oxygen Flow Rate, CFM NTP	19.2	10.3 - 33.4
Gas Purities, %		
Aerobic Vent O_2	68.9	31.5 - 91.5
Anaerobic Vent CH_4	49.1	35.5 - 62.5
CO_2	33.1	24.2 - 49.5
O_2	1.6	0 - 4.5
pH		
Feed	6.00	5.5 - 6.9
Aerobic	7.09	6.6 - 7.7
Anaerobic	7.30	6.7 - 7.65

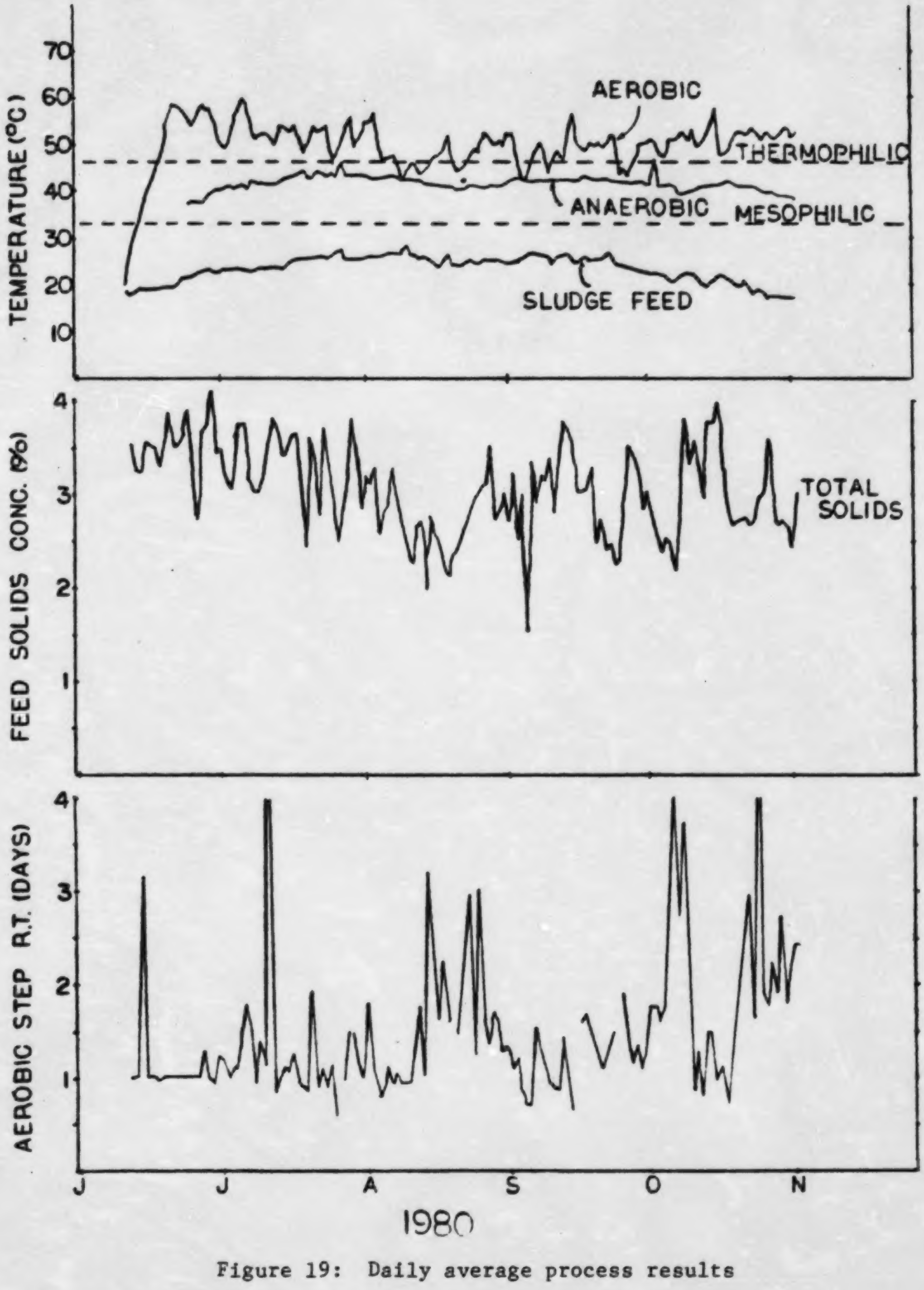


Figure 19: Daily average process results

Further test results gathered as the test program continued during the period of November 1980 to January 1981 illustrate the importance of high feed solids concentration. In the latter half of November the feed solids concentration at the Hagerstown plant began to increase to the 2.4% to 3.2% VS range (see Table 4). This occurrence was most likely the result of lower wastewater temperature which enhances solids setteability and retards the rate of nitrification and/or methanation taking place in the thickener sludge blanket. Whatever the cause, the final weeks of November saw a substantial improvement in overall system performance which continued through January. Although solids data for much of this time period is lacking it can be seen that the aerobic step was able to easily maintain temperatures in the 50 to 60°C range while operating at hydraulic retention times as low as 0.45 days. Furthermore, the amplitude of temperature fluctuations in the aerobic step was substantially diminished despite continued wide variations in sludge feed flowrate. The excellent performance of the dual digestion system at these higher solids concentrations is made all the more remarkable by the subfreezing ambient conditions which existed during much of this time period.

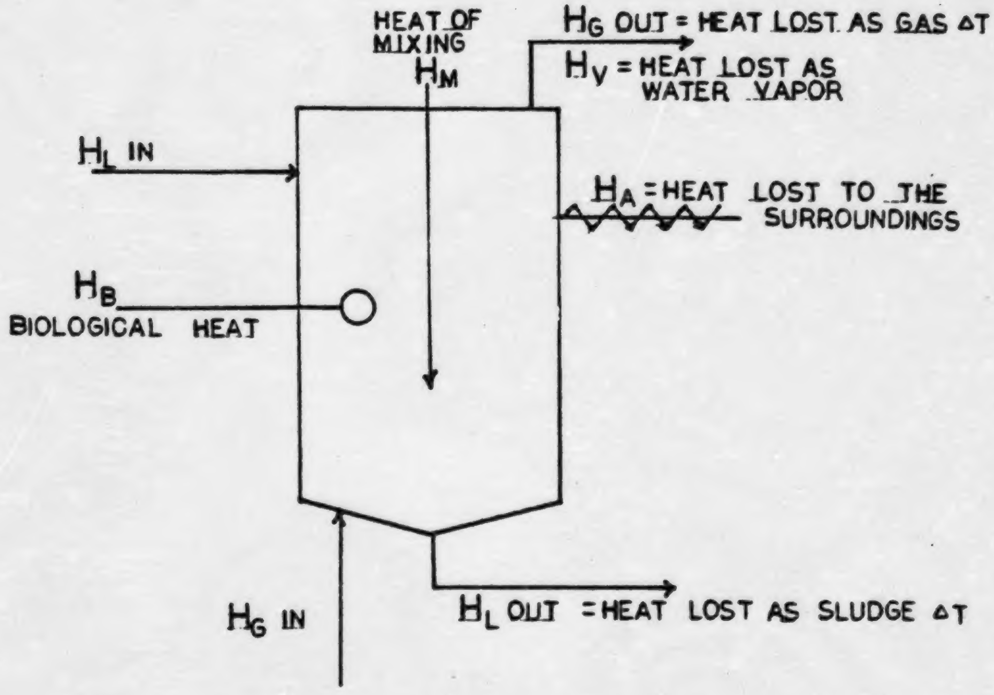
TABLE 4. HAGERSTOWN DUAL DIGESTION SYSTEM-WEEKLY AVERAGE DATA-WINTER OPERATION

PARAMETER Week of	11-03	11-10	11-17	11-24	12-01	12-08	12-15	12-22	12-29	01-05	01-12
Aerobic Retention Time, Days	1.8	1.69	—	0.97	1.06	0.73	0.66	0.68	0.68	0.53	0.45
Aerobic Step											
Feed Gas Flow, CPM	13.25	14.2	13.6	14.6	14.2	17.0	16.3	15.1	11.8	20.8	18.9
Vent Purity, % O_2	64.5	70.5	75.2	35.9	42.2	31.9	32.5	47.4	48.9	68.3	—
Temperatures, °C											
Feed	17.5	16.5	13.9	14.5	14.7	15.3	13.7	10.9	9.9	8.2	9.4
Aerobic	54.0	50.7	46.8	55.3	54.0	53.6	53.1	55.6	55.7	55.4	54.8
Ambient	10.7	6.6	2.08	3.8	4.3	6.7	-2.7	-3.2	-6.2	-7.0	-5.4
Solids Concentration, %											
Feed TS	3.28	2.96	3.01	3.79							
VS	2.64	2.38	2.48	3.16							
Aerobic TS	2.41	2.21	1.84	2.66							
VS	1.85	1.70	1.40	2.14							
Anaerobic TS	1.95	1.91	—	1.5							
VS	1.41	1.39	—	1.11							
pH											
Feed	6.06	5.9	6.17	5.74							
Aerobic	7.06	7.11	7.15	—							
Anaerobic	7.2	7.2	7.25	7.27							
High Shear											
Power, kW	18.3	18.2/ 13.0	13.1	15.0	14.7	15.0	15.3	15.0	14.8	14.7	14.7
RPM	32.3	32.2/ 28.5	28.4	28.5	28.5	28.4	28.3	28.4	28.6	28.5	28.5

AEROBIC HEAT OF REACTION

The aerobic digestion of organic wastes using high purity oxygen has been found to be a very efficient sludge heating process. Although part of the chemical energy contained in the biodegraded organic matter is used for cell growth and maintenance, the remainder is released as heat through oxidation of soluble substrate to carbon dioxide and water. It is the conservation of this liberated heat which allows thermophilic temperatures to be achieved and maintained in the first step of the dual digestion system.[6]

The net amount of heat produced expressed as BTU's per pound of volatile solids removed has been calculated on a weekly basis from a heat balance around the Hagerstown aerobic reactor as illustrated in Figure 20.


HEAT OF MIXING H_M
H_G OUT = HEAT LOST AS GAS ΔT
H_V = HEAT LOST AS WATER VAPOR
H_L IN
H_A = HEAT LOST TO THE SURROUNDINGS
H_B BIOLOGICAL HEAT
H_G IN
H_L OUT = HEAT LOST AS SLUDGE ΔT

$$H_M + H_B = \Delta H_L + \Delta H_G + \Delta H_V + \Delta H_A$$

Figure 20: Heat Balance

The heat input to the reactor consists of the heat generated by biological oxidation (H_B) and from the power input of the high shear mass transfer device (H_M). The heat output includes the heat loss due to the temperature difference between the cold feed and hot effluent (H_L); the heat loss in the aerobic vent gas which is the sum of the sensible heat (H_G) and the heat loss due to the vaporization of water (H_V), and the heat loss to the surroundings (H_A). The procedures and assumptions used in these calculations are summarized in Appendix B.

Figure 21 presents weekly average aerobic heats of reaction as a function of percent volatile solids reduction. Superimposed on the results of this study is the range of aerobic pilot plat data obtained at Union Carbide's Tonawanda Laboratories. The Hagerstown values span a range of 2980-9490 Btu's per pound of volatile solids removed and fall in the center of the band of previous data. The result of a least squares power fit of the Hagerstown data yields the following equation:

$$\underbrace{\text{Average Btu/lb } VS_R}_{\text{Aerobic Heat of Reaction}} = (1.84 \times 10^5) \times \underbrace{(\%\ VS_R)^{-1.05}}_{\text{Percent Aerobic Volatile Solids Removed}} \qquad (1)$$

(The above equation is empirical and should not be used to extrapolate removals below ~ 10%.)

Although the bulk of the weekly data fall in the high volatile solids removal (and subsequent low aerobic heat of reaction) region, Figure 21 does illustrate the dependence of aerobic heat of reaction on the extent of volatile solids removal implied by Equation (1). The fact that this relationship exists indicates that the components of sludge organic waste can be very different in energy content. Apparently the more readily oxidizable waste components contain more energy per unit mass and thus produce a relatively greater effect on temperature.

Due to the persistence of low influent solids concentrations at the Hagerstown Demonstration Plant, the percentage of volatile solids removed in the aerobic step has been higher than that required for normal dual digestion system operation. In the test phase described in this report aerobic volatile removals ranged from 15 to 50% as opposed to projected design values of 10 to 15% with higher feed solids concentrations. Figure 21 and Equation (1) both suggest that an aerobic heat of reaction of 15,000 Btu/lb VS_R is attainable at 10% volatile solids reduction. Referring to the heat balance illustrated in Figure 20 it can be seen that lower solids concentrations affect the aerobic reaction temperature by increasing the volume of liquid (H_L) which must be heated up by biological oxidation (H_B). The higher the volatile solids concentration of the influent sludge the smaller the fraction which must be aerobically reduced to attain thermophilic temperatures. This is limited only by the mass transfer capacity of the aeration device or the reaction kinetics of the aerobic digestion process.

A comparison of the relative magnitudes of full-scale and pilot plant heat losses and inputs is presented as Table 5. The table reveals that the major component in the heat balance is the quantity of energy required to raise the influent sludge to thermophilic temperatures. Chief differences between full and pilot-scale balances seem to lie in the fraction of biological heat lost to the surroundings and in the relative magnitude of the mechanical to biological heat inputs. Neither of these conclusions is unexpected since the surface area to volume ratio decreases with increasing reactor size allowing a considerable reduction in heat loss to the surroundings (H_A) while an increase in oxygen utilization with sludge depth accounts for mechanical input (H_M) and gas phase (H_G + H_V) differences.

TABLE 5. HAGERSTOWN VERSUS PILOT PLANT - RELATIVE HEAT LOSSES AND INPUTS

Hagerstown 06-16-80 to 10-27-80	
Sludge Heating (H_L)	522 x 10^4 Btu/Day
Wall Losses (H_A)	10.9 x 10^4
Gas Phase Losses (H_G and H_V)	3.34 x 10^4
Total Losses (H_{TL})	536 x 10^4
Mechanical Heat Input (H_M)	121 x 10^4
Biological Heat ($H_B = H_{TL} - H_M$)	415.2 x 10^4 Btu/Day

	Hagerstown	Pilot Plant
H_M/H_B	.291	.704
H_A/H_B	.026	.303
(H_G and H_V)/H_B	.008	.104
H_L/H_B	1.26	1.30

VOLATILE SOLIDS REMOVAL AND AEROBIC DIGESTION KINETICS

The dual digestion system has been demonstrated to be an efficient means for reducing the quantity of organic matter in waste secondary sludge. Volatile solids removals at the Hagerstown Demonstration Plant averaged 27.2% in the aerobic stage at a retention time of 1.4 days and 41.6% overall at a system retention time of 21.3 days. The overall removals compare well with the performance of the 25 to 50 day retention time anaerobic digesters previously used at the Hagerstown Wastewater Treatment Plant which averaged

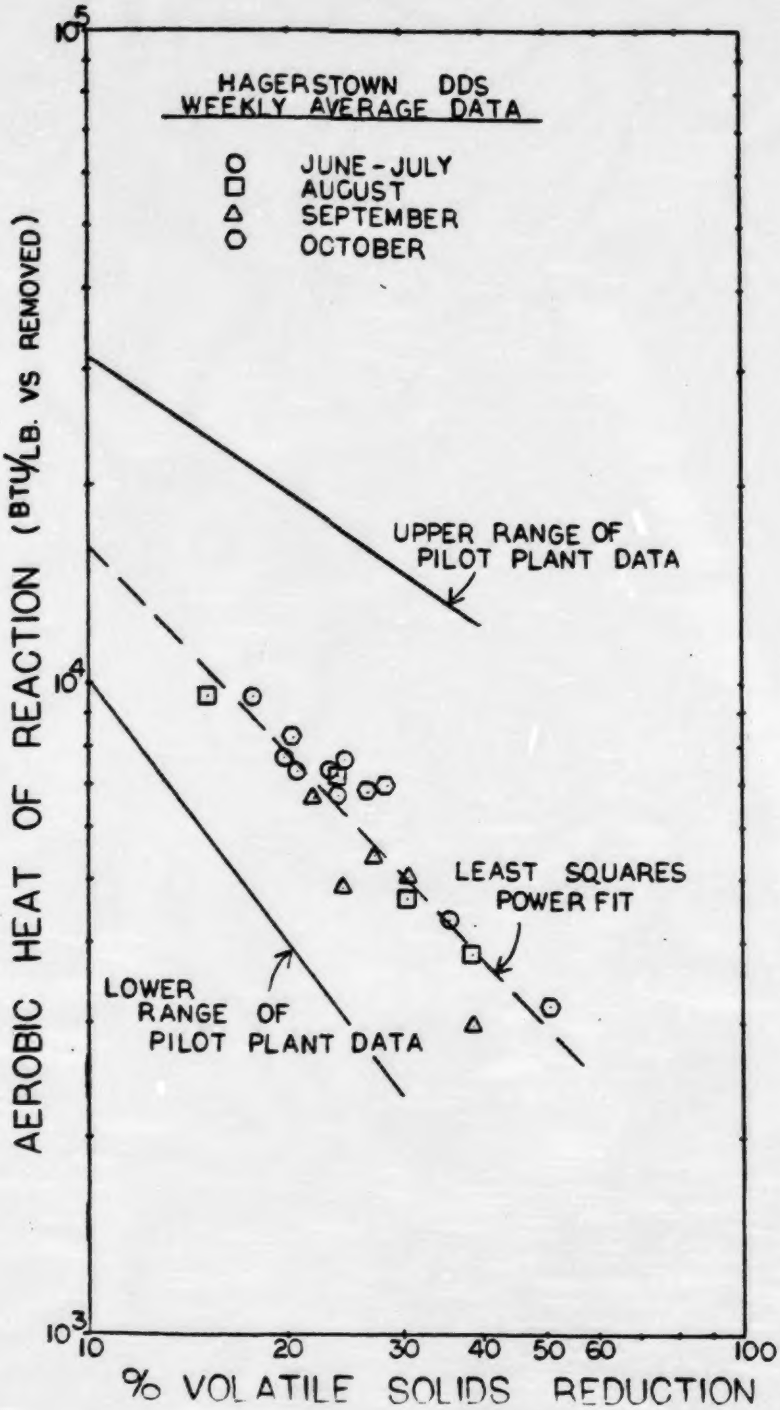


Figure 21: Aerobic heats of reaction.

43.5% volatile solids removal in the period 01-76 to 09-79 (Table 6). These conventional anaerobic digesters were arranged in two parallel sets with a primary and secondary digester in series. Primary digesters have a 50 foot diameter and a 24.5 foot depth and a total capacity of 396,552 gallons, while secondary digesters have a 50 foot diameter and 22.5 foot depth for a total capacity of 367,178 gallons. These floating cover reactors were mixed by gas recirculation. Although equipment for sludge heating was in place, it is not known to what extent this was used during the period under study.

Bench-scale degradability tests presented in Table 7 indicate that the maximum biodegradability of the influent volatile solids (BVS) was on the order of 58.6% for the dual digestion system. Thus the biodegradable solids reduction relative to the total reduction possible, was 46.8% in the aerobic stage and 70.9% overall. This data confirms that the dual digestion system can effectively stabilize sludge to the same extent as a long retention time (15+ days) anaerobic system.

The proper design of the aerobic step of the dual digestion system requires a knowledge of the kinetic rate constant (K_D) as well as the heat of reaction. Although the heat of reaction dictates the digester temperature range that can be attained, kinetics determine the residence time required to accomplish a fixed amount of volatile solids destruction. For the purposes of this study, the rate of solids digestion is assumed to be only a function of concentration and temperature and to be directly proportional to the biodegradable volatile solids concentration.(4, 5, 7) A simplified equation could be written as follows:

$$\frac{d[BVS]}{dt} = -K_D[BVS] \qquad (2)$$

[BVS] = concentration of biodegradable VS, %

K_D = reaction rate at temperature T, days^{-1}

t = time, days

The exact rate equation actually is more complex than the simplified version of equation (2) since the aerobic kinetic rate constant may also be influenced by:

- Oxygen mass transfer rate - enough dissolved oxygen must be available to the biological mass at all times.
- Presence of inhibitors - could adversely effect the biological reaction time.
- Sludge composition - the amount and relative biodegradability of organic wastes in the sludge could change the reaction constant.
- Nature of microorganisms - differences inherent to various strains of mesophilic and thermophilic bacteria in the way they break down and metabolize organic material could change K_D.

TABLE 6. HAGERSTOWN, MARYLAND - PREVIOUS ANAEROBIC DIGESTER PERFORMANCE

Year	Feed Sludge TS	Feed Sludge VS	Effluent TS	Effluent VS	Volatile Removal (%)	Volatile Acids (mg/l)	Total Alkalinity (mg/l)	Temperature °C
1976	3.94	3.19	1.89	1.34	58.0	96.3	3830	29.8
1977	3.37	2.73	2.23	1.63	40.4	672.8	3546	27.0
1978	3.31	2.62	2.24	1.59	39.2	356.5	3540	29.7
1979 through September	3.67	2.92	2.22	1.57	46.4	242.0	4050	29.7

Anaerobic Retention Time 25-50 days

TABLE 7. HAGERSTOWN FEED SLUDGE - BIODEGRADABLE VOLATILE SOLIDS (BVS) *

BVS NUMBER	15			19			20		
SAMPLE DATE	05-14-80			07-22-80			07-22-80		
	Day	TS	VS	Day	TS	VS	Day	TS	VS
	0	3.5	2.87	0	3.28	2.44	0	3.25	2.43
	4	2.48	1.92	3	2.98	2.19	3	2.50	1.75
	8	2.73	1.60	6	2.68	1.95	6	2.27	1.63
	14	2.00	1.52	10	2.46	1.76	10	2.13	1.52
	19	1.79	1.34	14	2.62	1.88	14	2.15	1.54
	22	1.72	1.28	20	2.58	1.83	20	2.24	1.52
	25	1.69	1.26	23	2.59	1.84	23	2.16	1.47
	28	1.61	1.21	29	2.55	1.80	29	1.90	1.24
	32	1.50	1.10	37	1.47	1.03			
	36	1.44	1.06	43	1.71	1.23			
	40	1.51	1.10	44	1.88	1.26			
	48	1.43	1.02	52	1.55	1.01			
	53	1.33	0.95						
	57	1.28	0.91						
$\%BVS_R$		68.3			58.6			49.0	

$$\%BVS_R = \left[\frac{\text{VS initial} - \text{VS final}}{\text{VS initial}}\right] \times 100$$

* SEE APPENDIX A FOR DESCRIPTION OF THE BVS TEST

Data by others (4) indicate that the kinetic rate constant of aerobic digestion is a strong function of temperature (see Figure 22). The reaction rate constant at 50°C is over two times that at 20°C. The operation of the first step of the dual digestion system in the thermophilic range (above 45°C) is thus conducive to high kinetic reaction rates. Two ideal kinetic reactor models can be used to determine rate constants from solids removal data. The ideal plug flow model assumes that the solids concentration of a sludge sample is a function only of its position in the aerobic reactor with the effluent concentration being the lowest. The resulting first order kinetic equation is:

$$\frac{[\mathrm{BVS}]\ \mathrm{out}}{[\mathrm{BVS}]\ \mathrm{in}} = 1 - K_D \cdot t \tag{3}$$

The second kinetic model is that of a single stage, ideal continuous stirred tank reactor (CSTR). In this model the solids concentration of any sample from the reactor is the same as that of the aerobic effluent. The resulting kinetic equation takes the following form:

$$\frac{[\mathrm{BVS}]\ \mathrm{out}}{[\mathrm{BVS}]\ \mathrm{in}} = e^{-K_D \cdot t} \tag{4}$$

Utilizing these equations along with the biodegradable fraction determined previously, reaction rate constants can be calculated for both the plug flow and CSTR models. The results of Hagerstown solids removal data weighted to fit the flow model (i.e. BVS_{out}/BVS_{in} equals 1.0 at time equals zero) are decay constants significantly higher than those of conventional aerobic digestion systems (Figure 22). Decay constants of 0.32 and 0.46 were determined for the plug flow and CSTR models, respectively (Figures 23 and 24). This could be due to a deviation from any of the assumptions and simplifications mentioned previously and may be inherent in the highly solids loaded, high temperature, partially degraded process the equations attempt to model. In any case, the indication is clear that the first step of the dual digestion system is not likely to be limited by simple reaction kinetics in achieving thermophilic temperatures at a 1 to 2 day retention time.

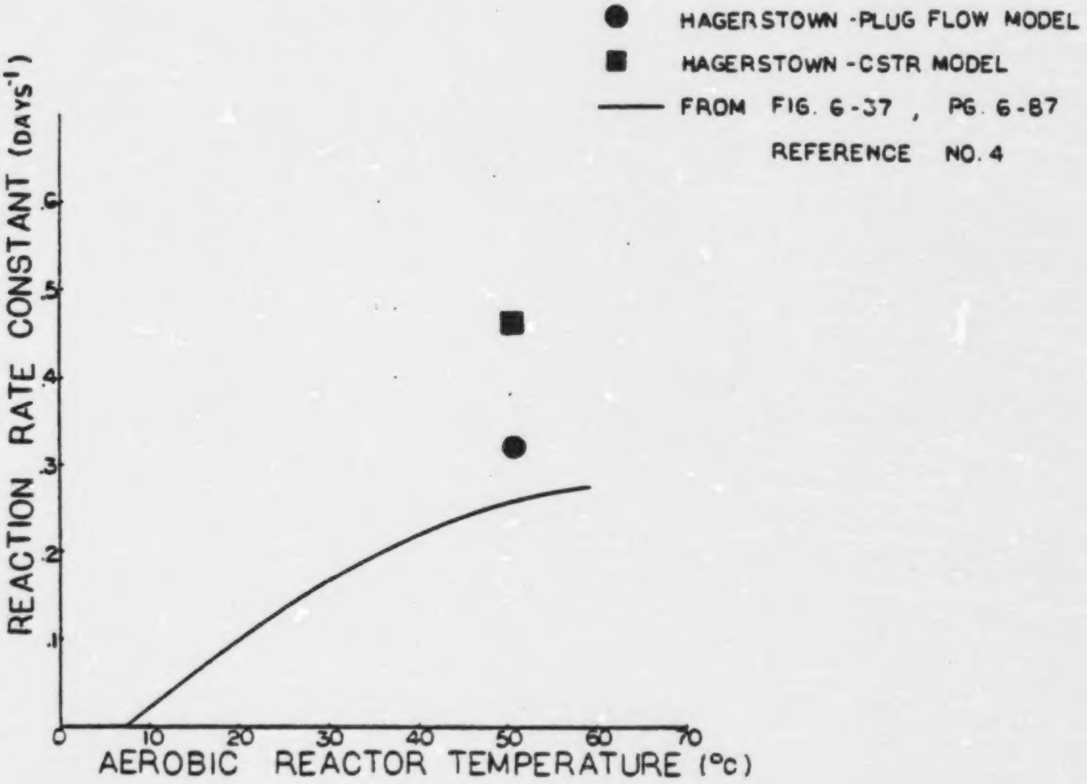


Figure 22: Aerobic decay constant versus retention time.

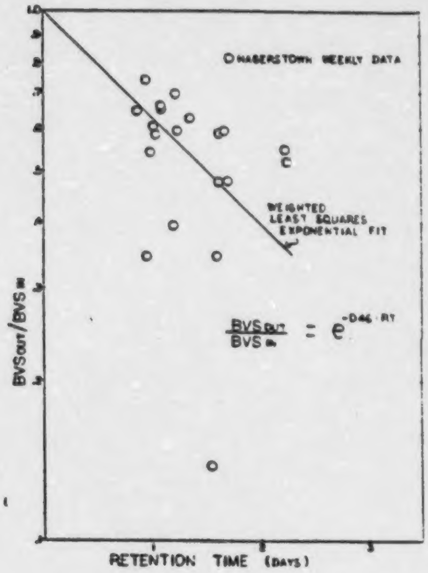


Figure 23: Determination of CSTR decay constant.

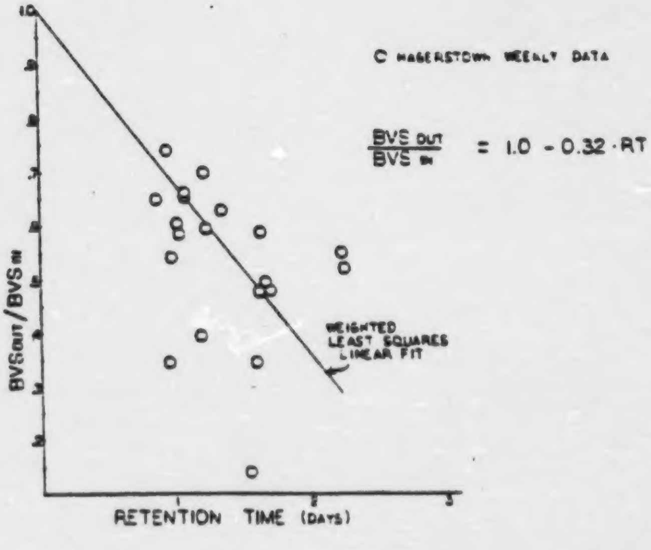


Figure 24: Determination of plug flow decay constant.

AEROBIC OXYGEN CONSUMPTION AND UTILIZATION

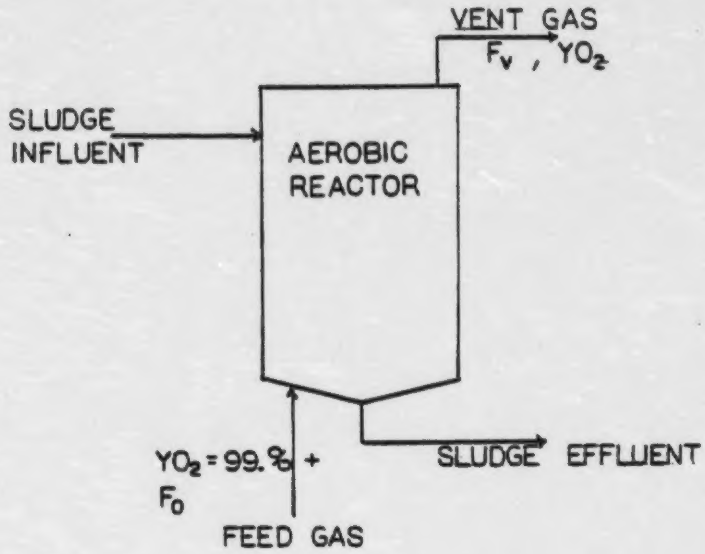


Figure 25: Oxygen Balance

The amount of oxygen required to maintain thermophilic aerobic metabolism is a key design parameter of a dual digestion system. This value, in conjunction with the feed oxygen utilization efficiency developed by the aeration device, defines the size of on-site oxygen production and storage capacity. Obviously the lower the oxygen consumption ratio (lbs oxygen consumed per lb of VS removed) and the higher the oxygen utilization (expressed as percent of feed oxygen which is absorbed by the biomass), the more economical the aerobic step design. During the course of the test program, tests were conducted at different shear rotational speeds to measure these parameters. Figure 25 illustrates the various process flows which were accounted for during each test. The oxygen feed from the liquid oxygen storage tank was 99.9% pure oxygen with the remainder being argon. The aerobic vent gas contains (in descending concentration) any unused oxygen, carbon dioxide produced during aerobic digestion, water vapor and traces of nitrogen and argon stripped from the influent sludge. The amount of dissolved oxygen in the reactor feed and effluent are negligible factors in the oxygen balance due to their low concentration (less than 0.5 mg/l) and low liquid to gas volumetric flow ratio.

Results of the oxygen balance tests are summarized in Table 8. As can be seen, the oxygen consumption ratio ranged from 1.62 to 1.8 pounds of oxygen per pound of volatile solids removed which agrees well with data published in literature for the thermophilic temperature range.(4,7)

Unfortunately the low oxygen utilization and high aerobic vent gas rates caused by low influent solids concentrations prevented an accurate completion of an oxygen balance around the aerobic reactor at 24 rpm. Figures 26 and 27 illustrate how the frequency of observed vent oxygen purities and oxygen feed flows compare to the average values for the oxygen balance tests of Table 8. The purpose of these illustrations is to demonstrate that the data taken during the oxygen balance tests are representative of long-term aerobic step operation.

Table 8: OXYGEN BALANCE DATA

PARAMETER	32.2 RPM	28.5 RPM	24 RPM
Date	06-24 - 08-03	08-14 - 09-10	08-04 - 08-13
Feed Oxygen Flow, CFM	17.1	21.1	27.4
Vent Oxygen Flow, CFM	5.7	11.5	—
Vent Oxygen Purity, %	70.0	73.2	82.3
Aerobic Retention Time, Days	1.11	1.58	1.08
Aerobic Temperature, °C	54.0	48.3	46.1
Feed Volatile Solids, %	2.63	2.23	2.15
Volatile Solids Removal, %	23.3	36.5	18.9
Lbs Oxygen Fed/Lb VS Removed	2.69	3.57	6.35
Lbs Oxygen Absorbed/Lb VS Removed	1.80	1.62	--
Oxygen Utilization, %	66.7	45.4	—

The high shear mass transfer device has been shown to be effective in thickened secondary sludge achieving over 65% utilization of the feed oxygen at 32.2 rpm. Reducing the speed to 28.5 rpm resulted in a drop in oxygen utilization to 45 percent and aerobic reactor temperature to approximately 48°C. Further reduction of aerator speed to 14 rpm caused additional deterioration of mass transfer performance and an observed difficulty in responding to daily fluctuations in feed flow. It should be noted however that these low speed tests coincided with a drop in feed solids concentration from 2.6% volatile solids down to 2.15% volatile solids. This fact contributed to the relatively poor performance at low speeds. Additional test results obtained for 28.5 rpm operation during a period of higher solid concentration (see Table 4) in the winter months indicate that the high shear mass transfer performance substantially improves when the aerobic step feed contains greater than 2.7% volatile solids. Aerobic vent oxygen purities in the 30% to 70% range were found with feed oxygen flows of 12-21 CFM. Further testing is required to confirm these low speed, high solids concentration results.

Figures 28 and 29 present daily and weekly average values for oxygen feed rate and vent purity.

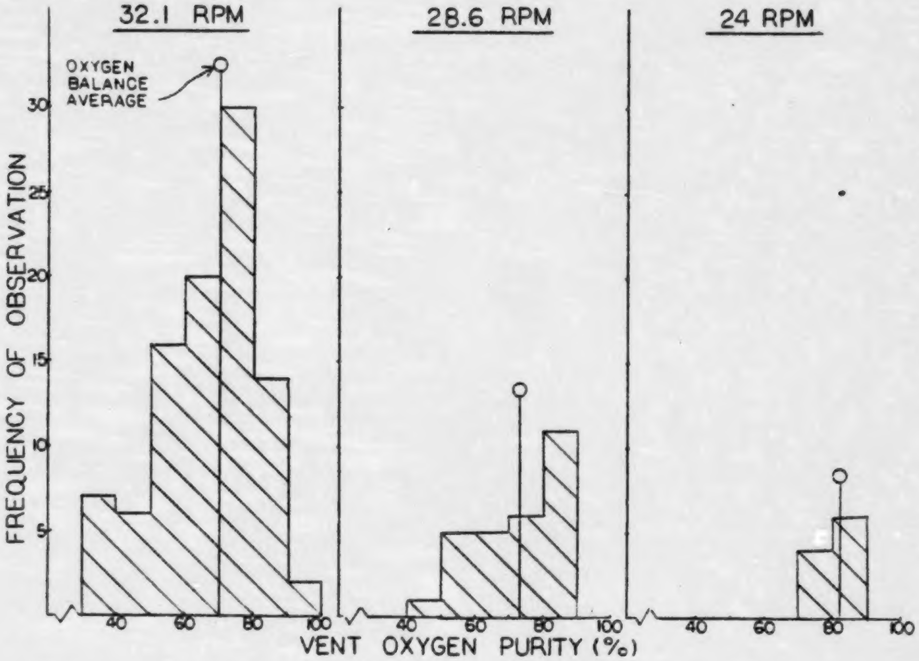


Figure 26: Vent oxygen purity - frequency of observation.

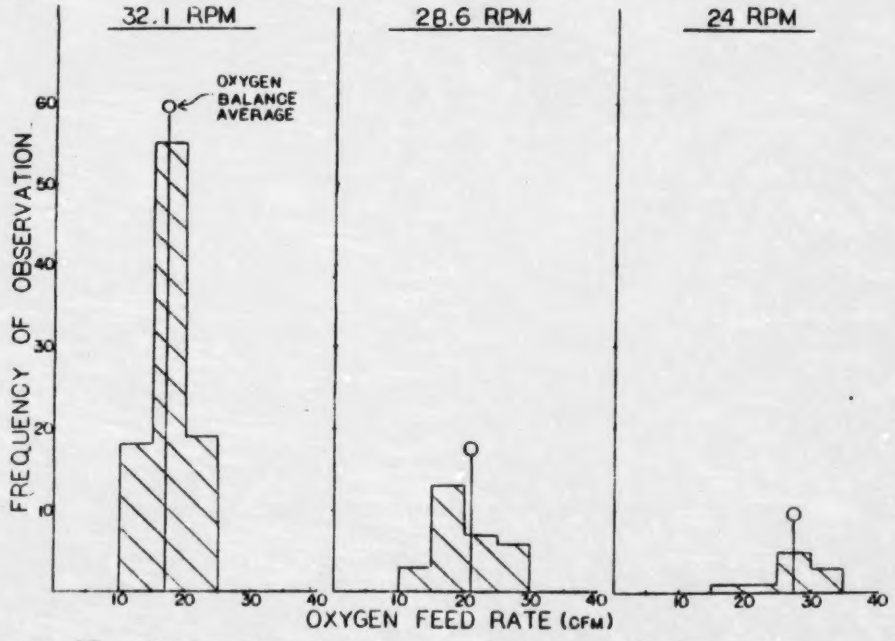


Figure 27: Feed oxygen flow rate - frequency of observation

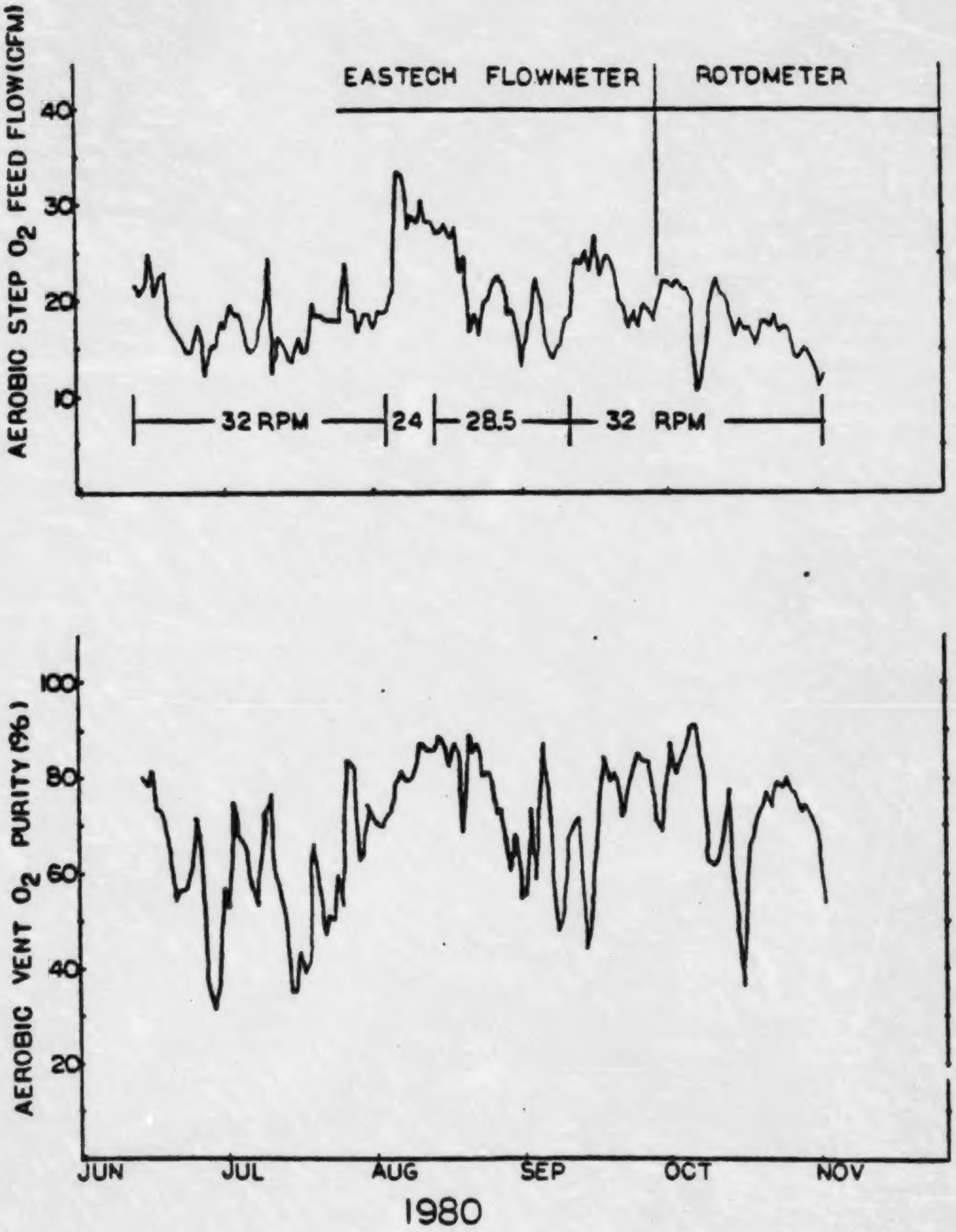


Figure 28: Daily average oxygen feed flow and vent purity

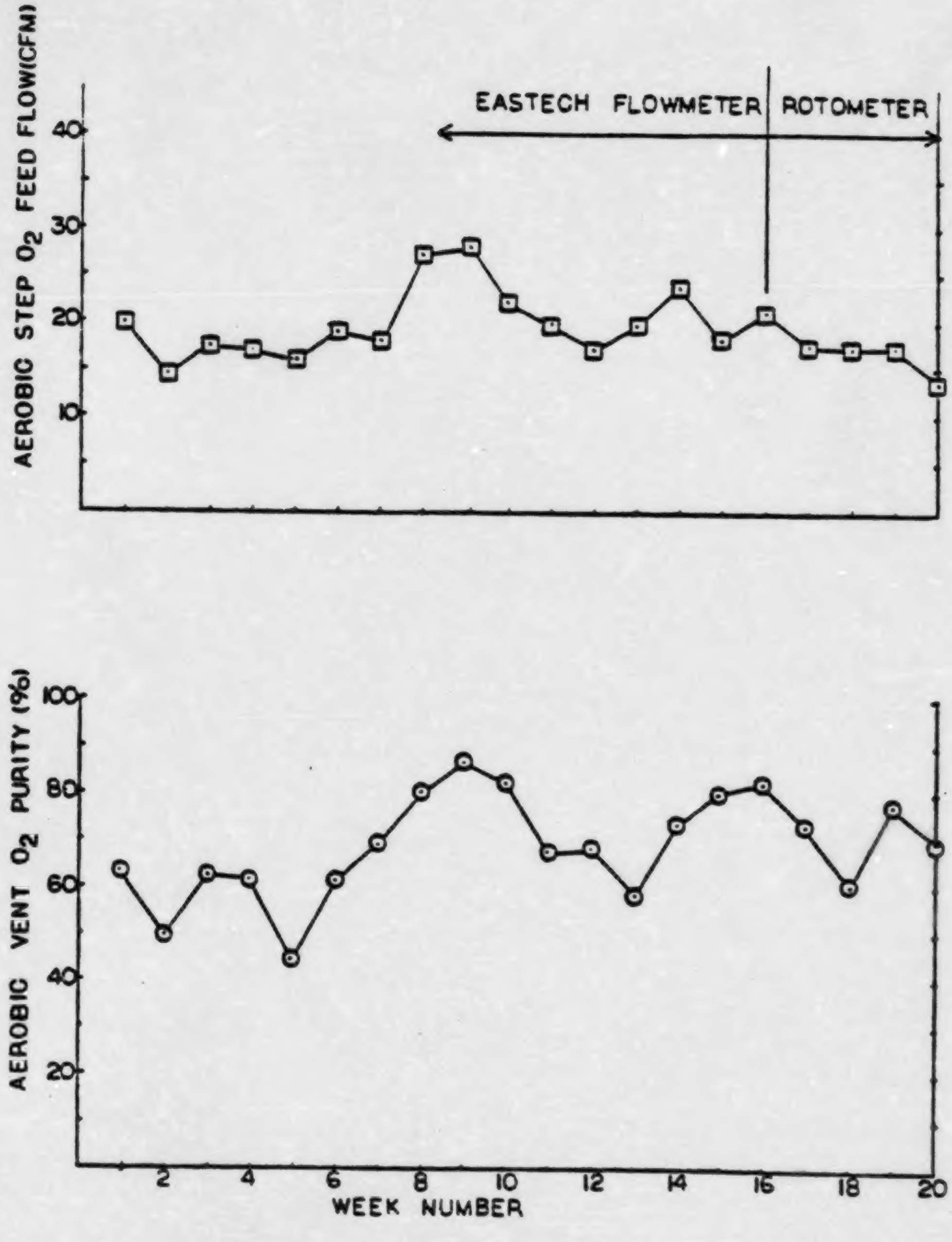


Figure 29: Weekly average oxygen feed flow and vent purity.

INDICATOR AND PATHOGENIC ORGANISMS REDUCTION

Sludge digestion processes, especially when operated in the thermophilic temperature range, have been found to significantly reduce the levels of pathogenic organisms.(4,9,12) The destruction or inactivation of such disease causing organisms is of particular concern when the ultimate disposal of the sludge is to be on cropland as is the case at Hagerstown, Maryland. The primary pathogens present at significant levels in typical domestic wastes can be classified into three groups:

- Bacteria
- Viruses
- Parasites

Indicator organisms from each of these three groups were used to estimate the reduction performance of the dual digestion system during the course of this test program. Individual test results and analytical procedures followed are contained in Appendices A, E and F of this report. Table 9 presents a summary of test conditions and pasteurization results for samples collected at various process locations.

Bacteria

Bacteria are single cell organisms which can grow and reproduce under a variety of environmental conditions. Among the primary groups of pathogens they are the only ones with the ability to reproduce outside of the host organism. Analyses were performed for the indicator organisms of Total and Fecal coliform, Fecal Streptococci and Salmonella Sp. by Dr. Vincent Oliveri of the School of Hygiene and Public Health, Johns Hopkins University.

Average results show significant reductions in indicator bacteria across the dual digestion system. In many cases the Salmonella results and sometimes even the Coliform and Streptococci levels approached their detectable limits of 3 MPN/100 ml and 1000 MPN/100 ml, respectively. Except for the Salmonella count which will be discussed later, the anaerobic effluent values compare favorably to similar analyses performed on the long retention time anaerobic digesters previously in use at Hagerstown which achieved only a single order of magnitude reduction in Coliform and Streptococci concentrations. When compared to other pathogen reductions achieved by full and pilot-scale digesters[4] the Hagerstown thermophilic aerobic and mesophilic anaerobic effluent bacteria concentrations fall in low to mid-range level. This is despite the fact that excellent reduction results seem easier to achieve in a pilot or bench-scale apparatus than in a full-scale plant.(4,9)

TABLE 9. SUMMARY OF PASTEURIZATION RESULTS

DUAL DIGESTION SYSTEM (06-16-80) - (10-27-80)

	Aerobic Feed		Aerobic Effluent		Anaerobic Effluent		Aerobic M.L.		Control Digester (03-31-80) + (04-14-80)		Shipment Sample (10-27-80)
									Feed	Effluent	
Indicator	Average	Range	Average	Range	Average	Range	Average	Range	Average	Average	
Fecal Coliform $\left\{\frac{\text{MPN}}{100\ \text{ml}}\right\}$	$6.6\text{x}10^7$	$2\text{x}10^7-1.4\text{x}10^8$	$4.3\text{x}10^3$	$1.7\text{x}10^1-1.4\text{x}10^4$	$9.5\text{x}10^4$	$1.4\text{x}10^4-4.9\text{x}10^5$	$3\text{x}10^4$	$2\text{x}10^3-7.8\text{x}10^4$	$2.5\text{x}10^7$	$6.4\text{x}10^6$	$2\text{x}10^3$
Total Coliform $\left\{\frac{\text{MPN}}{100\ \text{ml}}\right\}$	$4\text{x}10^8$	$1.7-8.4\text{x}10^8$	$8.4\text{x}10^6$	$2\text{x}10^3-3.5\text{x}10^7$	$1.1\text{x}10^5$	$1.4\text{x}10^4-4.9\text{x}10^5$	$4.5\text{x}10^4$	$1.0\text{x}10^3-1.3\text{x}10^5$	$4.6\text{x}10^8$	$5.1\text{x}10^7$	$2.3\text{x}10^3$
Fecal Streptocci $\left\{\frac{\text{Bacteria}}{100\ \text{ml}}\right\}$	$1.3\text{x}10^7$	$5.4\text{x}10^6-2.2\text{x}10^7$	$4.1\text{x}10^3$	$9\text{x}10^2-1.4\text{x}10^4$	$4.9\text{x}10^5$	$2\text{x}10^4-1.3\text{x}10^6$	$5.9\text{x}10^4$	$3.3\text{x}10^3-1.2\text{x}10^5$	$8.5\text{x}10^6$	$7.3\text{x}10^5$	$1\text{x}10^3$
Salmonella Sp $\left\{\frac{\text{MPN}}{100\ \text{ml}}\right\}$	205	15-1100	BDL*	BDL-9.1	109	9-460	BDL	BDL	35.5	21.7	BDL
Virus $\left\{\frac{\text{PFU}}{100\ \text{ml}}\right\}$	784	67-1164	<2.0	<1.25-<2.2	<2.5	<1.25-8.0	<2.0	—	197.5	26	
Ascaris $\left\{\frac{\text{OVA}}{100\ \text{g}}\right\}$	1 test showed 1 (0)**		2 tests showed 1 (1)		1 test showed 1 (0)		all tests 0 (0)		2 (0.5)***	12 (2)	
Toxocara $\left\{\frac{\text{OVA}}{100\ \text{g}}\right\}$	1 test showed 1 (0)		tests show 1-3 (0)		tests show 1-3 (0)		1 test showed 1 (0)		2 (0.5)	3 (0.5)	

Sample Test Conditions

Parameter	Average	Range
Feed Temperature, °C	22.4	16-25.5
Aerobic Temperature, °C	51.6	40.7-61.0
Anaerobic Temperature, °C	41.7	39.4-43.3
Aerobic R.T., days	1.6	0.8-4.4
Anaerobic R.T., days	22.9	8-59

---

* BDL = below detectable limit (Refer to Discussion)

** Number in parenthesis is the number of viable ova

*** Control parasite counts are in (ova/60 g)

**** Averages are arithmetic averages.

The extent of sludge pathogen reduction achieved by a biological stabilization has been found to be a function of reactor temperature, retention time and mode of operation.(9) It is important to note when viewing these results that the second step was operated as a mesophilic anaerobic digester before switching feed sources from raw secondary sludge to the effluent from the aerobic stage. Since the temperature of the second step never achieved the thermophilic limit (45°C) it is possible that bacteria such as Salmonella could reinoculate and recontaminate the anaerobic effluent sludge to some extent. This hypothesis is forwarded to explain why the concentration of Salmonella Sp. in the effluent of the anaerobic second stage is consistently greater than that of the aerobic first stage. Starting the anaerobic step "dry" or by operation of the second step at thermophilic temperatures for at least one day would remove this obstacle to increased reduction of pathogens.

In a similar vein, it can be seen that sludge samples taken from the aerobic reactor have significantly lower bacteria counts than samples taken from the aerobic effluent overflow pipe. Tests performed in September and October indicate that this is not a problem of insufficient reactor temperature or bacteria bypass due to the completely mixed nature of the aerobic tank, but instead most probably stems from bacteria recontamination in the external effluent piping. Sludge in this pipe cooled down in the interval between sludge charging. This problem is not insurmountable and requires only some modifications of the reactor hydraulic design.

During the latter phases of the test program an effort was made to pinpoint possible sources of recontamination in the sludge sampling technique. This took the form of extra operator care in sampling and in the handling of sludge sample cups, the replacement of sample tubing, the purging of sample lines by drawing off excess liquid and the coordination of sample timing with the reactor charging cycle to ensure representative samples of mixed liquor and aerobic effluent sludge. In addition, efforts were made to determine the extent of recontamination which occurred during sample shipment, if any. These corrections in sampling techniques were successful in bringing aerobic effluent and mixed liquor bacteria concentrations closer together. Acknowledging the sensitivity of the microbiological assay to technique and sampling procedure as well as the operational problems previously described which increased the variability of results, the dual digestion system demonstrated significant reductions in the concentrations of pathogenic bacteria in the Hagerstown waste secondary sludge.

Virus

Viruses are obligate parasites and as such can only grow and reproduce inside of a host cell. Although different strains of viruses show varying resistance to environmental conditions such as temperature and pH, their inability to reproduce provides the potential for high removal rates in sludge stabilization processes without fear of recontamination. Samples analyzed by the U.S. Environmental Protection Agency Municipal Environmental Research Laboratory in Cincinnati, Ohio show an excellent viral kill in boththe aerobic and anaerobic stages of the dual digestion system. Anaerobic step effluent concentrations of less than 2.5 plaque forming units (PFU) per 100 ml of sludge sample is considerably below the average of 26 PFU/100 ml observed in the control tests or the 100 to 1000 PFU/100 ml for digested sludge published in reference (4). No attempt was made to distinguish between various virus strains in the sludge sample analysis.

Parasites

Parasites are single cell animals (protozoa) and worms (nematodes and helminths) which grow and reproduce in the digestive tract of the host organism. During the course of this study the prevalence of two species of roundworm ova, Ascaris and Toxocara, was investigated. Analyses were performed by the Biological Laboratory, University of Cincinnati under contract with the U.S. Environmental Protection Agency Municipal Environmental Research Laboratory in Cincinnati, Ohio. Unfortunately there is a wide variation in the levels of parasite concentration in sewage sludge at different locations in the United States. At Hagerstown the occurrence of roundworm ova in the waste secondary sludge was intermittent and rare. The large scale of this program as well as the ultimate disposal of the effluent sludge on cropland precluded the seeding of the influent sludge with the indicator organisms. Although the results are inconclusive due to the low to nonexistent feed ova concentrations, it can be said that when Ascaris and Toxocara ova did appear in the aerobic reactor or the anaerobic step effluent they were in an inactive (nonviable) state.

DUAL DIGESTION SYSTEM STABILITY AND FLEXIBILITY

Much has been written concerning process stability for both aerobic and anaerobic digestion. In general, anaerobic digestion is the least stable of the two processes because of its delicate microbial balance between acid forming bacteria and the slower growing methane forming bacteria.(2,3,4,10) Anaerobic digestion is basically a two-step process. In the first, carbohydrates, proteins and fats are hydrolyzed to fatty acids, alcohols, ammonia and glycerol. This step is performed by a broad class of organisms known as "acid formers". The second step of converting fatty acids to methane and carbon dioxide is done by specialized methanogenic bacteria which are slow growing and sensitive to changes in pH. Process difficulties occur when the balance of the system is upset by thermal or solids loading shocks. The acid formers being the hardier of the two can respond more quickly to such fluctuations causing an increase in the volatile acid content of the anaerobic reactor. If left unchecked, this increased acid concentration can depress sludge pH which further inhibits the growth of methanogenic bacteria and a vicious cycle begins. In the past this sensitivity has been compensated for by tight anaerobic temperature control, increased solids mixing, longer retention times and sometimes the use of multistage digesters.(2,3,4)

The dual digestion system reduces the vulnerability of the anaerobic process to thermal and solids loading fluctuations by placing a high rate aerobic digester upstream. Since aerobic digestion is known to be an inherently more stable process, this allows the anaerobic step to be designed close to its optimum retention time.(3,6) The activity of the aerobic organisms varies almost proportionately to the influent loading, therefore the first step dampens fluctuations in the feed sludge characteristics so that the anaerobic stage receives a preheated feed which is nearly uniform in composition and pH. The elevated temperature of the thermophilic first step is maintained by high rate oxidation of the highly degradable waste fraction to cell matter and heat while more difficult-to-degrade wastes undergo a more extensive solubilization. Thus, the thermophilic aerobic first step acts as a "load leveler" and increases the quantity of soluble organic material readily available for methane generation in the anaerobic step. The moderating influence of the aerobic step on anaerobic feed solids concentrations is documented in Table 2 where aerobic feed concentrations range from 1.5 to 4.1% TS and 1.2 to 3.3% VS while the aerobic effluent solids concentrations vary from 1.6 to 2.8% TS and 1.2 to 2.2% VS.

Another consequence of the thermophilic aerobic digestion pretreatment step is an increase in the pH and alkalinity of the sludge fed to the anaerobic step (Figure 30, Table 10). In theory, the aerobic step organic compounds are oxidized to carbon dioxide and water. Proteins decompose and the resulting nitrogen is converted to ammonia since nitrogenous bacteria are not active at elevated temperatures. This free ammonia reacts with some of the available carbon dioxide to form ammonium bicarbonate, thus increasing the buffering capacity and pH of the sludge entering the second step.

Throughout the Hagerstown test program the dual digestion system experienced wide variations in sludge feed flow (0.6 to 8.8 day aerobic retention time) and solids content for reasons previously mentioned. In addition to this operational problem the system was subject to at least one major upset towards the end of July. The fact that the stability of the dual digestion system, as indicated by such process parameters as pH, alkalinity and volatile acids concentration (Figure 31), remained within the desired operating ranges for the bulk of the test program illustrates the potential for reliable operation.

Aerobic Step Stability

Figure 30 presents weekly average pH values for the aerobic reactor and sludge feed, while Table 10 summarizes analytical results obtained at the Hagerstown Plant. There is a significant increase in total alkalinity along with an elevated pH in the first step of the dual digestion system. An increase in the ammonia concentration bears out the bicarbonate formation mechanism described previously. There is also an increase in soluble con- centrations of other nutrients such as phosphorus as well as the soluble COD concentration of the aerobic effluent sludge. This is most probably due to the load leveling action of the aerobic process in breaking down long chain organic wastes in the sludge feed.

Anaerobic Step Stability

The stability of a conventional anaerobic digestion process may be judged against a number of process indicators.(10,11) Chief among these are reactor pH, alkalinity, volatile acid concentration, methane purity of the vent gas and carbon dioxide purity of the vent gas. For the anaerobic step at Hagerstown all of these parameters stayed well within typical operating ranges as presented in Figures 31 and 32 as well as Table 10. This lends credence to the theory that the anaerobic digestion process can perform well even at reaction temperatures between the traditional thermophilic and mesophilic ranges.(11) Sludge total alkalinity and volatile acids concentrations averaged 3649 and 663 mg/l, respectively, while anaerobic pH averaged 7.3. Digester vent gas purities were disappointing due to substantial leaks which developed in the gas seal of the fixed cover digester. Despite these problems the methane averaged 49% and carbon dioxide 33% of the vent digester gas over the course of the entire test program. Based on the weekly average vent gas measurements contained in Table 3, the sum of the CH_4, CO_2 and O_2 gas fractions in the anaerobic vent decreased during the months of July and August. Since digester gas is typically 35% CO_2, 65% CH_4 plus traces of other gases such as H_2S, N_2, etc., it is hypothesized that infiltration of air through leaks in the digester gas seal caused an increase in the nitrogen content of the sludge gas. The old fixed cover digester was replaced with a renovated floating cover anaerobic digester in mid-November. During the transfer, the anaerobic sludge temperature decreased to 36°C so that in the subsequent start-up of the new digester a heat exchanger was used to increase temperatures to the 42-44°C range. From early December through January the anaerobic digester was able to maintain this temperature range without the heat exchanger or any other external heat source. Operation was reported as stable with digester vent gas being continuously flared, an indication of high methane purities.

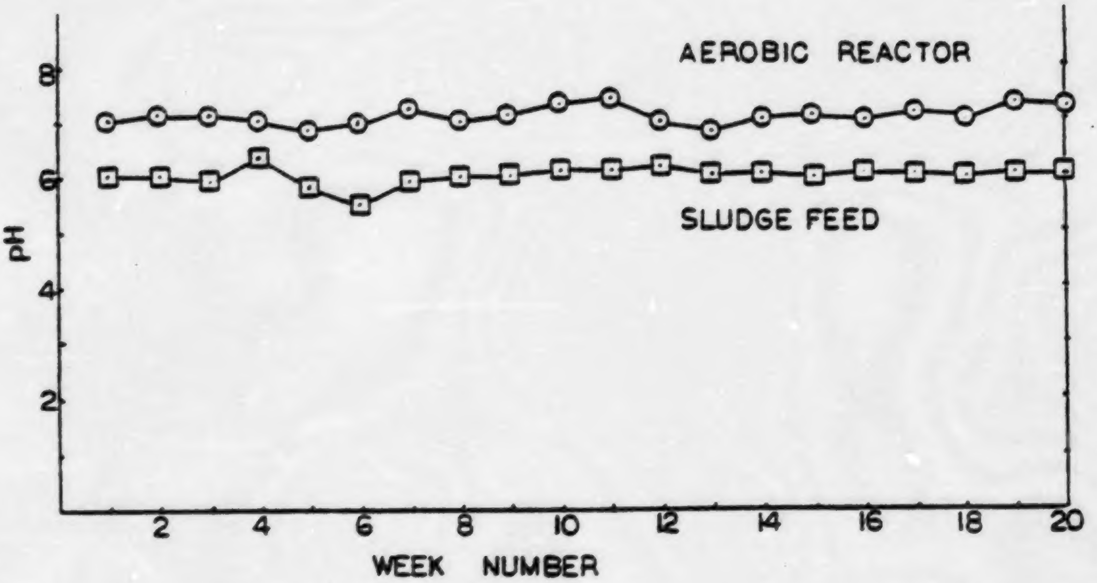


Figure 30: Weekly average feed and aerobic pH.

TABLE 10: HAGERSTOWN ANALYTICAL RESULTS

SAMPLE	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	NO. OBS.	HIGH	LOW	AVG.		
RAW FEED												
Alkalinity	805	854	738	633	815	827	54	1260	360	751	MG/L	$CACO_3$
TKN	1963.2	2147.6	1862.3	2281.7	-	-	23	3059	1397	2081	MG/KG	WET
NH_3	126.9	130.2	54.9	66.1	-	-	26	465	42.5	95	MG/KG	WET
Phosphorus - T	283.2	322.2	296.4	179.9	-	-	22	407	120	282	MG/KG	WET
Phosphorus - S	193.4	175.8	101.4	74.9	-	-	25	220	52.6	134	MG/KG	WET
COD - WET	2.48	1.79	0.92	0.85	-	-	35	2.73	0.65	1.31	G/KG	
COD - DRY	745.9	35.4	27.5	32.1	-	-	35	1216	18.3	93	G/KG	
AEROBIC EFFLUENT												
Alkalinity	2950	2294	1928	1744	2143	2460	54	3616	890	2136		
TKN	-	2074	1822.6	2064	-	-	19	2789	1670	2006		
NH_3	-	636.8	474.1	627.9	-	-	22	1151	393	590		
Phosphorus - T	298	344.4	313.5	165.9	-	-	24	686	138	295		
Phosphorus - S	293.3	262.5	205.4	128.3	-	-	24	321	106	217		
COD - WET	10.39	7.23	4.02	4.68	-	-	34	11.93	2.13	5.78		
COD - DRY	718.1	27.5	21.0	25.4	-	-	34	1186	15.8	86		
ANAEROBIC EFF												
Alkalinity	3710	3497	3807	3311	3481	3643	65	4100	2900	3559		
Volatile Acids	360	1058	625	452	471	299	64	1830	265	623		

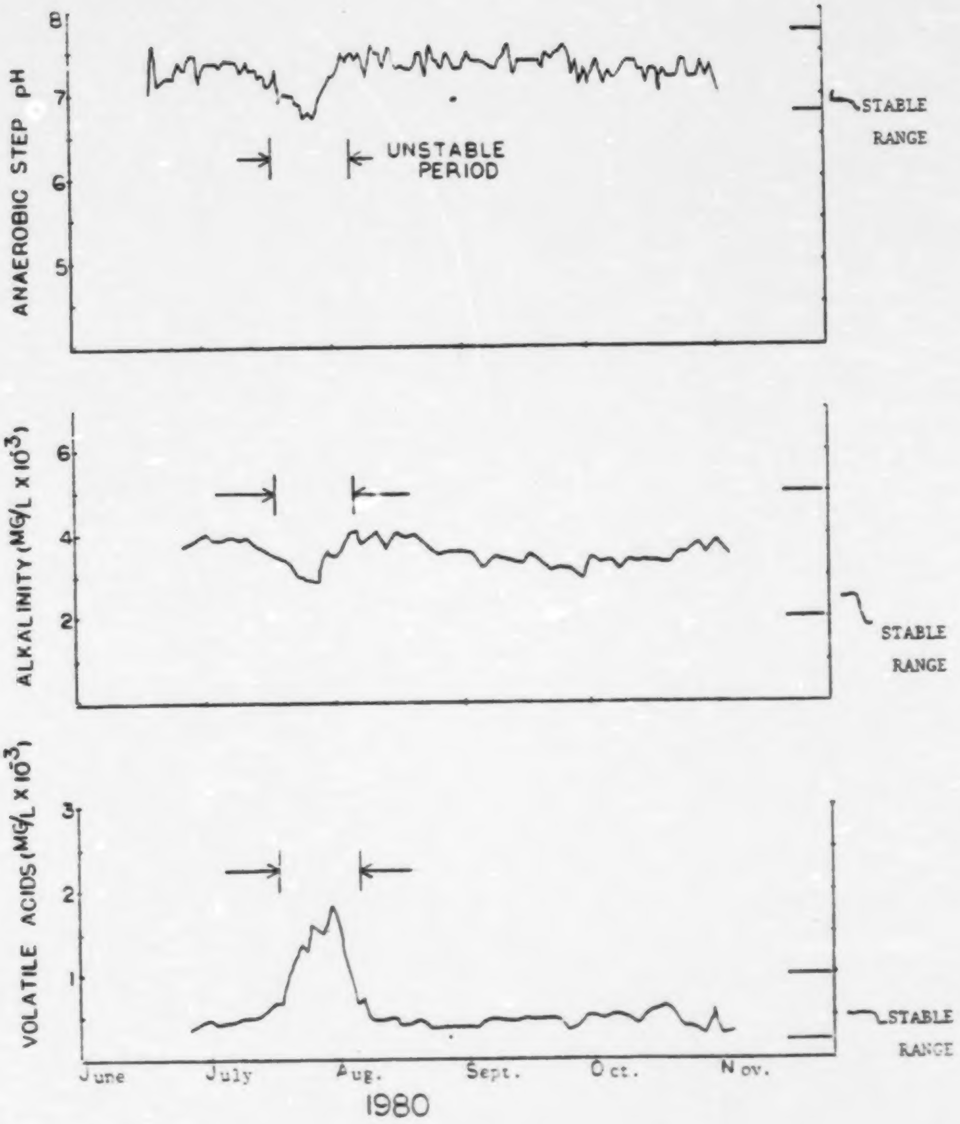


Figure 31: Anaerobic step stability indicators.

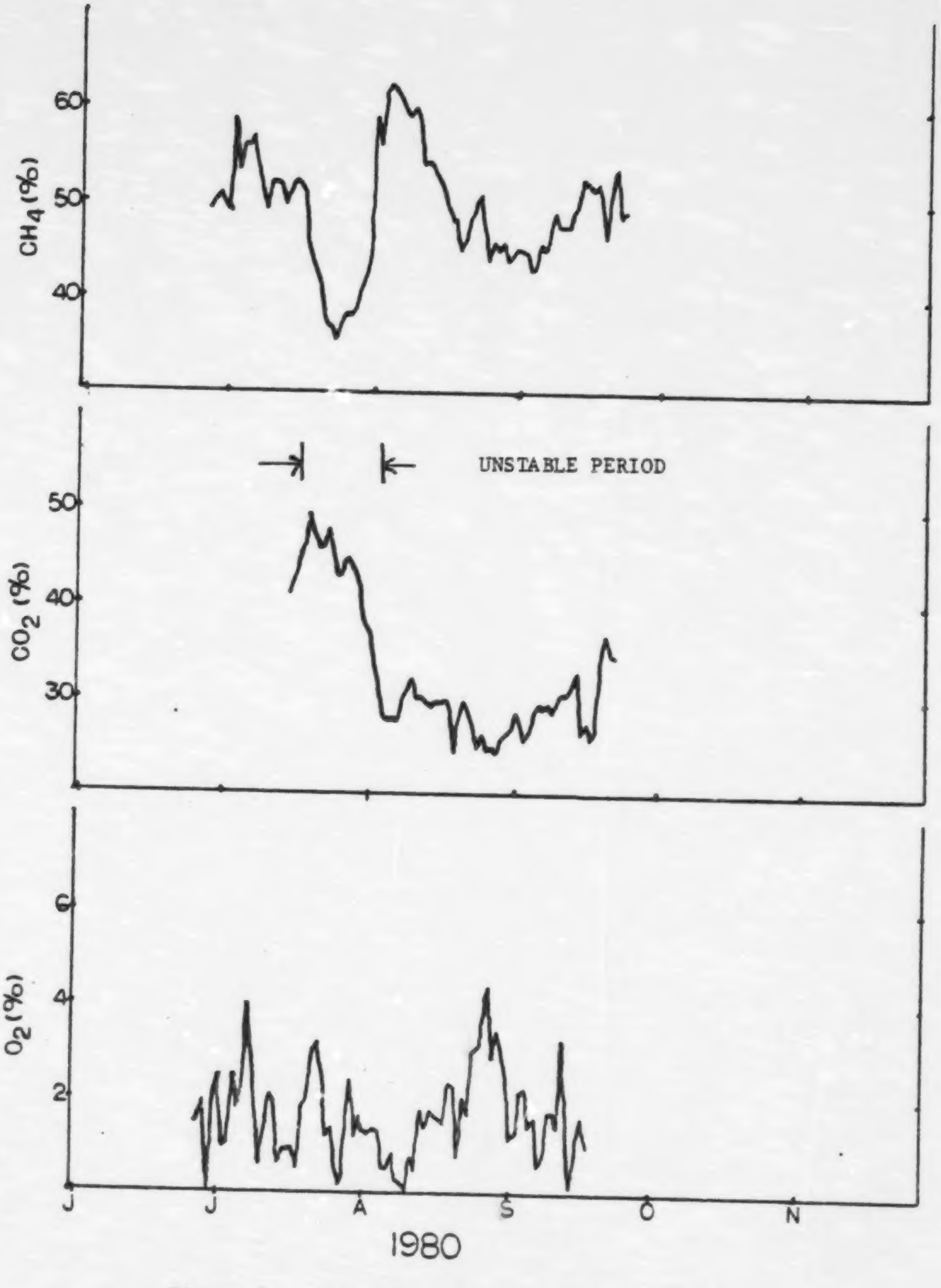


Figure 32: Anaerobic step vent gas purities.

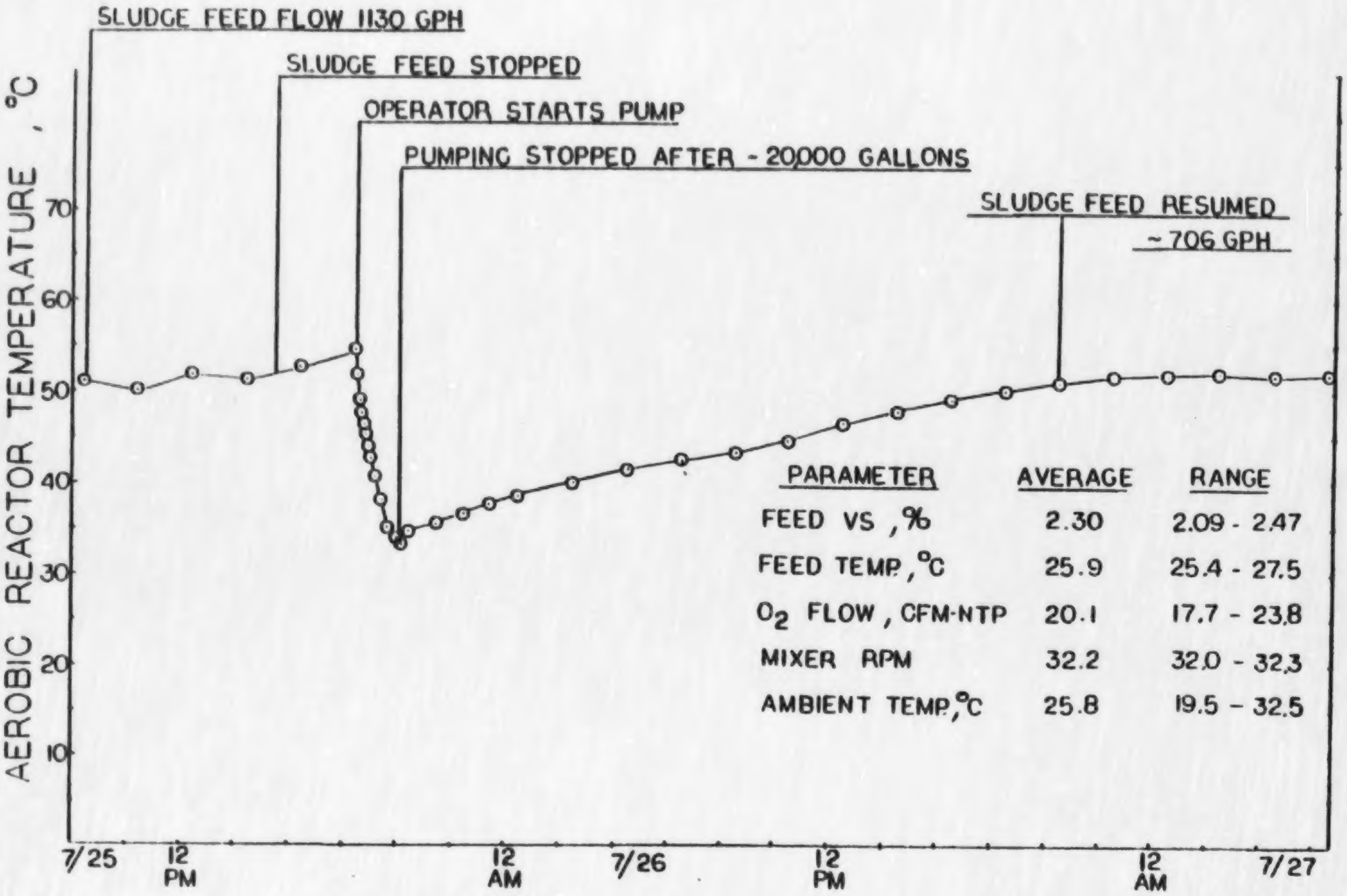


Figure 33. Aerobic step flexibility.

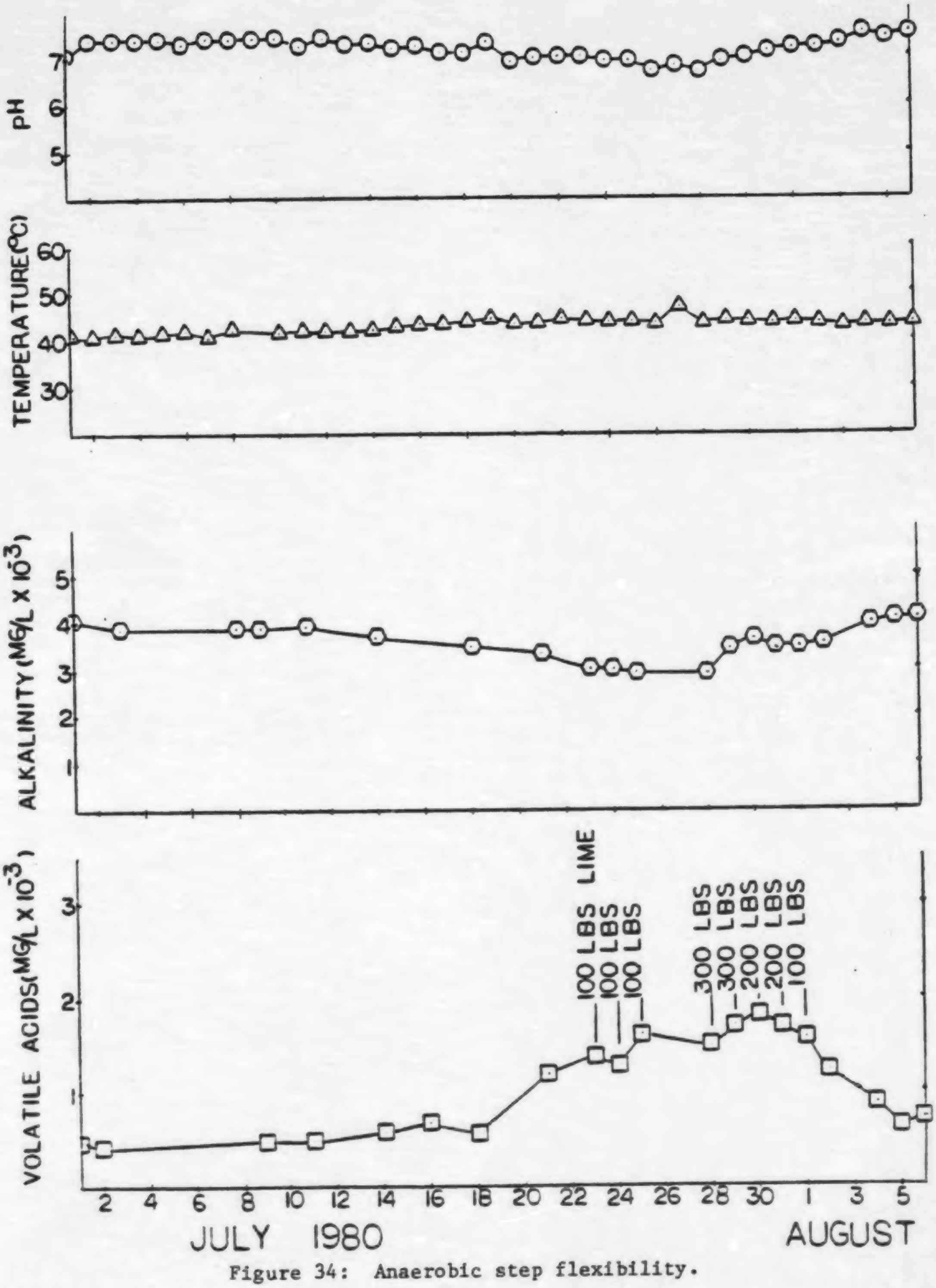


Figure 34: Anaerobic step flexibility.

Figure 31 also illustrates the short period of unstable operation experienced by the dual digestion system while operating at a short retention time. Because of problems with the sludge pumping system the anaerobic retention time fluctuated sharply during the last half of July. This fluctuation was compounded by an inadvertent upset of the dual digestion system. On the evening of July 25th, the operator accidentally pumped approximately 20,000 gallons of raw secondary sludge to the dual digestion system over the course of a three-hour period. This represents an extreme thermal and solids loading shock to the system and caused the aerobic reac- tor temperature to drop from approximately 55°C down to approximately 34°C (Figure 33). This upset necessitated the suspension of sludge feed flow and an increase in the flow of oxygen to the first step. The flexibility of the aerobic process was demonstrated by the fact that under these conditions thermophilic temperatures were regained after only 24 hours allowing the resumption of normal, if more cautious, operation. The anaerobic step (Figure 34) which had already been suffering from previous flow variations, was plunged deeper into an unstable region by this upset. An increase in reactor volume (required to provide a gas seal over the influent sludge pipe) along with a moderate amount of lime addition for a period of one week returned the system to normal. It is expected that an anaerobic reactor design tailored to the needs of the dual digestion system as regards reactor volume and mixing, would provide even greater stability during flow upsets.

SECTION 7

SYSTEM OBSERVATIONS

For optimum performance of the dual digestion system high feed sludge solids concentrations are preferred. It has been found that conventional sparged aeration devices have difficulty in achieving efficient operation at solids concentrations above 4% due to the non-Newtonian, pseudoplastic behavior of thick sludge and its effect on bubble dynamics.(2,6,8) In such fluids the viscosity is a function of the amount and rate of shear applied. Therefore as a bubble leaves the high shear region of a conventional sparged impeller system it penetrates into increasingly viscous layers of sludge. As the viscosity of the surrounding fluid increases, the terminal-rise velocity of the bubble decreases from surface drag. Any bubbles subsequently generated by the sparger have a tendency to follow the path of least resistance, namely, the low viscosity "tunnel" formed by the wake of the previously ascending bubble. Since the terminal velocity of this second bubble is faster it eventually overtakes the original bubble in the mechanism of bubble coalescence. When this occurs the volume of the bubble increases faster than its apparent surface area. When enough bubbles coalesce buoyancy overcomes drag and the bubble-rise velocity increases over that of the smaller bubbles from which the larger bubble was formed. As a result the bubble residence time and the gas-liquid interfacial area are reduced and adequate oxygen transfer cannot take place at reasonable power inputs.

The concept of the high shear device is to minimize bulk inertial mixing of sludge and concentrate instead on developing thin, highly turbulent zones along the bubble-rise path to reduce bubble coalescence. The primary energy draw of the thin (low width to diameter ratio) shear blades is to overcome viscous drag rather than for bulk fluid mixing which is eventually dissipated as heat in the reactor. Since liquid pumping is reduced more of the power input is utilized for mass transfer rather than being lost to viscous dissipation. The low settling velocity of thick sludges combined with the relatively short hydraulic retention time in the aerobic reactor prevent any solids separation from occurring.

The ability of the shear device to generate small bubbles and high interfacial area in thick sludge was borne out by the persistent generation of dense foam at the aerobic sludge surface at Hagerstown. The extent of this foam generation depends to an unknown degree on a number of different factors such as sludge type, treatment history, solids concentration and operating temperature. At Hagerstown the foam became particularly troublesome during periods of low solids or temperature transition. The addition of small quantities of silicone based anti-foam agent when required was found to alleviate the problem. The causes, occurrence, and possible solutions to the aerobic foam problem should be addressed in future research.

PRELIMINARY EXPERIENCE

Initial testing of the aerobic stage, begun in January 1983, proved how difficult the mixing of thick, thermophilic sludge could be. The original high shear device blade design for the Hagerstown project were of flat, rather than circular, cross-section. Each blade was flame cut from a 13/16 inch thick steel plate and had an overall length of 66 inches. These blades were arranged in four pairs attached to the shaft by four hubs. Upon start-up it was observed that the sludge exerted a greater than expected influence on system power draw. Although high shear power draws were expected to be on the order of 1.2 to 1.8 times those measured in tapwater, observed results were 3 to 4 times those measured in secondary effluent. Such an increase in power draw is postulated to be due not only to the increased viscous drag in high solids concentration sludge but also to differences between the two fluids in their effect on applied forces and induced blade movements. The shaft horsepower draw measured in secondary effluent was within 10% of that predicted by small scale tapwater tests in Union Carbide's Tonawanda Laboratories.

As the tests continued through the month of January, gradual decrease in power draw and mass transfer performance were noted. The program was terminated approximately one month after start-up due to excessive shaft vibration and gearbox movement. After draining and inspection of the reactor interior it was discovered that 7 out of 8 blades had broken near the shaft hub. The remaining blade at the bottom of the shaft was undoubtedly the cause of the severe shaft imbalance. Metallurgical examination of the blades revealed that the initial mode of failure for all blades was stress corrosion cracking at a stress point near the hub which quickly transformed into corrosion fatigue, the dominant failure mode. This event precipitated the redesign of the blades to their present configuration with a circular cross-section to minimize blade lifting and eliminate stress focal points near the hub. Furthermore, greater attention was paid to materials selection, welding and stress relief.

In May 1980 the aerobic reactor was re-started with the new blade design only to be shut down after 3 weeks due to a wall baffle failure. A wall baffle had become dislodged and damaged the lowest pair of shear blades. The original plywood baffles were replaced by coated carbon steel baffles with a "beefed up" support structure.

Finally the system was started in June and has continued without further mechanical failures.

POWER VERSUS ROTATIONAL SPEED

During the course of the Hagerstown test program the rotational speed (rpm) of the high shear device was varied from 24 to 32 rpm in an effort to evaluate the extent of oxygen mass transfer at various conditions. As described in the Process Results' Section of this report, feed oxygen utilizations in the 45-65% range were obtained at 28.5 and 32 rpm. Figure 35 illustrates the daily average motor power of the high shear device at the speeds tested. Based on shaft strain gage readings an overall motor, belt drive and gearbox efficiency of approximately 72.5% was obtained so that the following table of shaft speeds and power draws could be generated.

TABLE 11. HIGH SHEAR POWER VERSUS RPM

RPM	Motor Power KW	Shaft Horsepower SHP	Power Density SHP/1000 Gallons
32.1	18.8	18.3	1.12
28.6	12.6	12.2	0.74
24.2	8.6	8.35	0.51

MIXING AND MASS TRANSFER

For the two shaft speeds for which oxygen balance data was collected, transfer efficiencies were calculated on a dissolution basis. The value does not include the power expended to separate oxygen from air, only the power required to dissolve it in sludge. Under this assumption, actual transfer efficiencies of 3.1 - 3.9 lbs oxygen/shp.hr were obtained for operation at 32 and 28.6 rpm. Normalizing to standard conditions (i.e. YO_2 = 21%; P_e = 1 atm, 20°C) yields an average dissolution efficiency of only 0.12 lbs oxygen/shp.hr. Additional data taken during the winter months (see Table 4) tends to support the observation that higher influent solids concentrations enhance rather than hinder the dissolution efficiency of the high shear device. However the main conclusion to be drawn from this study is that the high shear device has sufficient oxygen transfer capacity to achieve and maintain thermophilic temperatures in the aerobic step at short hydraulic retention times and reasonable power densities (0.5 to 1.1 shp/1000 gallons).

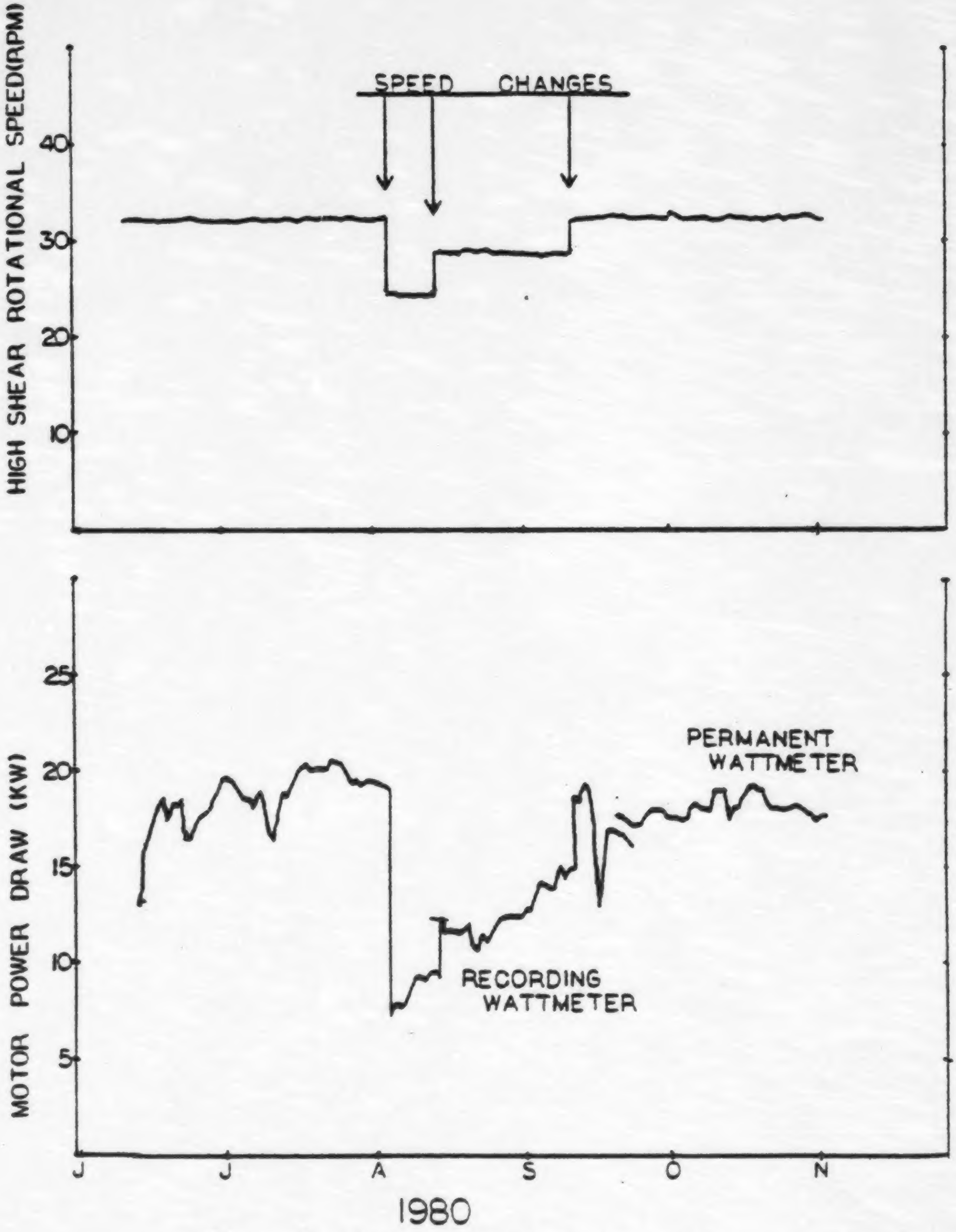


Figure 35: Daily average power draw and rpm.

Although the thin blades of the high shear aeration device are designed to minimize bulk fluid motion in the aerobic digester considerable mixing does take place. Temperature and solid samples data indicate that the hydraulic pattern in the first step approaches that of a completely mixed reactor. Thermocouples placed at varying depths in the aerobic reactor (Figure 14) all read temperatures within 1.5°C of one another at virtually all times (Table 12). Furthermore solids samples taken from varying depths (Figure 14) also show little variability both before and after a sludge feed cycle (Table 12). Therefore, in spite of its shape and the large wall baffles installed in the aerobic tank, the high shear device does seem to mix the sludge. The mixed nature of the aerobic digester was probably a key factor in the rapid recovery following the July 25th upset. It prevented a complete washout of thermophilic organisms which an ideal plug flow reactor would have allowed.

TABLE 12. MIXING PROFILE DATA

SOLIDS DATA

Test Date	Tap #	% TS	% VS	Tap #	% TS	% VS
08-15-80	BF 1	1.78	1.42	AF 1	-	-
	2	1.98	1.52	2	1.82	1.56
	3	1.96	1.60	3	1.91	1.53
	4	1.93	1.58	4		
	Sludge Feed	3.18	2.60	515 gph		
08-15-80	BF 1	1.78	1.42	AF 1	-	-
	2	1.93	1.54	2	1.89	1.56
	3	1.96	1.60	3	1.91	1.53
	4	1.93	1.58	4	1.99	1.62
	Sludge Feed	3.18	2.60	556 gph		

TEMPERATURE DATA

Test Date	TC 1	TC 2	TC 3	TC 4	TC 7
06-23-80	57.0	57.1	57.5	57.5	57.3
08-15-80	45.3	45.8	46.2	46.1	45.8
09-07-80	48.8	48.3	49.5	49.5	49.1

BF = Before Feed

AF = After Feed

SECTION 8

SLUDGE END USE AND DISPOSAL

During the time period documented in this report the City of Hagerstown Water Pollution Control Plant was undergoing a transition phase. As part of the overall facility improvement an upgrading of the sludge management program was instituted of which the dual digestion program was only a part. The effluent sludge from the anaerobic step was pumped to an open sludge holding tank from where it was sent either to drying beds or to land application. The City of Hagerstown has for some time(13) utilized waste sludge as a soil conditioner. Five 2-1/2 ton modified U.S. Army tank trucks transported the wet sludge to approximately 24 farms in surrounding Washington County which grow crops that are not directly used for human consumption. The low metals content of the sludge due to stringent industrial pretreatment standards, combined with the extensive pathogen reductions and biological stabilization achieved with the dual digestion system, make farmland application an attractive alternative to disposal at a sanitary landfill.

More recently, a mechanical dewatering step has been added to reduce the volume of sludge transported. Lime and ferric chloride are added in the holding tank and the sludge is then introduced to a plate press from which a cake of 40-45% solids based on total weight is obtained. This cake is then suitable for land application using a manure spreader. Efforts have been made to get official recognition of the product sludge as composting material.(14)

In addition to sludge management, the City has also embarked on an ambitious plant of energy conservation. The methane generated in the anaerobic step is free to be utilized year round due to the autothermal nature of the aerobic step. This gas is used, after scrubbing, for the heating and cooling of plant buildings and to power a modest sized fleet of alternative fuel vehicles. Other projects are presently under study to increase the energy utilization efficiency of the Hagerstown plant.

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APPENDIX A

ANALYTICAL PROCEDURES

ANALYTICAL DATA

Appendix D is a summary of daily analytical results from the Hagerstown Dual Digestion Demonstration Plant. These tests were performed on-site in the wastewater treatment plant laboratory by City of Hagerstown personnel. Pro- cedures followed those outlined in Standard Methods for the Examination of Water and Wastewater - 14th Edition, with the exception of volatile acids determination which were determined by the direct titration as described by Dilallo and Albertson (JWPCF Vol. 33 No. 4, April 1961. pp 356 - 365).

BVS TEST

Biodegradability test results presented in Table 7 were performed at UCC's Tonawanda Laboratories and consist of the measurement of the reduction of the volatile solids content in a sludge sample over a period of time in a bench-scale apparatus. A 2 to 3 liter sample of sludge is placed in a small plexiglas reactor. The reactor is placed in a 50°C water bath and fed high purity oxygen which has been saturated with water vapor. At the beginning of each test and at appropriate time intervals samples were withdrawn and analyzed for total and volatile solids content as per Standard Methods. The point at which the volatile content of the sludge levels off indicates the biological stabilization of the sludge and the maximum reduction of volatile solids for the system. From this value an estimate of the ultimate degradability and biological fraction of a sludge's volatile solids can be determined.

HAGERSTOWN SLUDGE SAMPLES - MICROBIOLOGICAL ANALYSIS

Sample Collection and Shipping

Samples were collected in sterile one liter containers by Hagerstown sewage treatment plant personnel. The samples were chilled in a freezer and then shipped in an insulated container with ice packs to the laboratory, where they were immediately processed. All samples were processed within eight hours of collection.

Microbiological Procedures

Total and Fecal Coliform--

Total and fecal coliform were determined by the MPN procedure given in Standard Methods (1975), using lactose broth with five tubes per dilution for the presumptive test, brilliant green lactose bile broth for the confirmed total coliform test, and EC medium for fecal coliform.

Fecal Streptocci--

Fecal streptocci were determined by the plate count method using KF Streptococcus agar, as given in Standard Methods (1975).

Salmonella sp--

MPN Salmonella was determined by a modification of the procedure given by Oliveri (1977), which was based on the procedure given by Kenner and Clark (1974). Three replicate aliquots of 100, 10, 1 and 0.1 ml of sludge were innoculated into dulcitol selenite broth and incubated at 40°C. A flow diagram of the procedure is shown in Figure A-1. After incubation for 24 hours, an aliquot from each DSE broth tube was streaked on XLD agar. Typical Salmonella colonies (black or red) were picked by toothpick and innoculated on the different agars shown in Figure A-1 for biochem- ical tests. DSE samples that were negative for typical colonies were re- streaked after 48 hours incubation. Colonies that were oxidase, malonate and phenylalanine deaminase negative and positive for mannitol and lysine decarboxylase were innoculated onto trible sugar iron agar. Colonies yielding typical Salmonella (KA++) reactions on TSI were tested against polyvalent Salmonella antisera. Each DSE tube was assigned as positive or negative for Salmonella on the basis of the above procedure and the MPN was determined.

Procedures for the Recovery of Eggs from Sludge--

The procedure of the Biological Laboratory of te University of Cincinnati was followed for the recovery of parasitic eggs from sludge. Each sludge (100 g) sample was passed through a U.S.A. Standard Testing Sieve No. 35 and the retarded material washed with water. The sieved sample was returned to a 250 ml plastic centrifuge bottle and spun at 1000 rpm for 5 minutes in an IEC, Model PR-2 centrifuge. The supernate was discarded. One hundred ml of 3% lactalbumin hydrolysate was added and shaken to resuspend the sludge pellet. The mixture was spun at 1000 rpm for 5 minutes and the lactalbumin hydrolysate supernate was discharded. The sludge was resuspended and spun again to remove the lactalbumin hydrolysate. The supernate was discarded. Water was added to the sludge pellet to make a final volume of 50 ml.

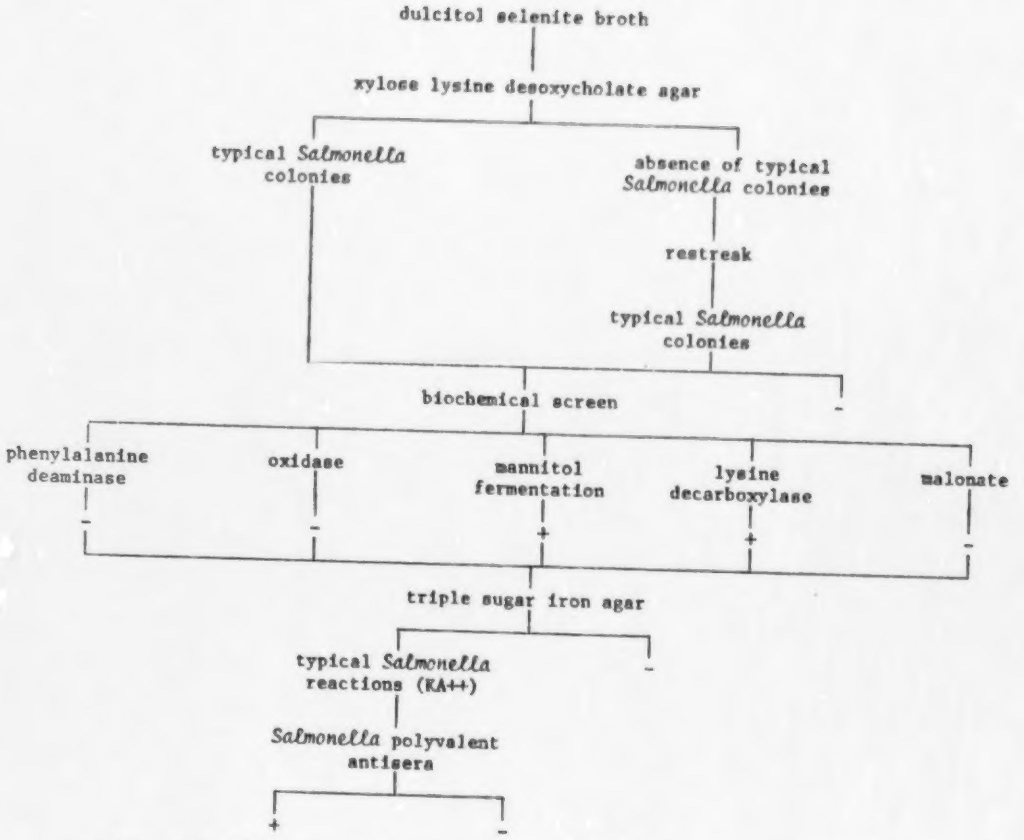
dulcitol selenite broth
xylose lysine desoxycholate agar
typical *Salmonella* colonies
absence of typical *Salmonella* colonies
restreak
typical *Salmonella* colonies
biochemical screen
-
phenylalanine deaminase
oxidase
mannitol fermentation
lysine decarboxylase
malonate
-
-
+
+
-
triple sugar iron agar
typical *Salmonella* reactions (KA++)
-
Salmonella polyvalent antisera
+
-

Figure A-1 Flow diagram for MPN procedure for enumeration of *Salmonella*.

Continuous sucrose density gradients, specific gravity 1.26 through 1.00 were poured with the aid of a peristaltic pump (Gilson Minipuls 2) into 250 ml polycarbonate centrifuge bottles. Fifty ml of sludge were layered on top of the gradient. The gradients were spun at 1800 rpm for 15 minutes. The supernate, containing the eggs, was poured into 250 ml conical bottom, plastic centrifuge bottles and diluted with water. The bottles were mixed and then spun at 1000 rpm for 5 minutes. The supernate was removed by aspiration and the pellet was washed 3 times. After the final wash, the eggs were resuspended in 5 ml of autoclaved 0.1 normal H_2SO_4 and placed into a 100 x 15 mm sterile, polystyrene Petri dish. The Petri dish remained in a humidified atmosphere at 25°C until the parasite eggs were embryonated.

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Oliveri, V. P., Kruse, C. W., Kawata, K. and Smith, J. E. 1977. Microorganisms in Urban Stormwater. U.S. EPA-600/2-77-087.

Standard Methods (1975) American Public Health Assoc., American Water Works Assoc., Water Pollution Control Federation. Standard Methods for the Examination of Water and Wastewater.

APPENDIX B

HEAT BALANCE CALCULATION

Liquid ΔT $H_L = 8.34\ Q_L\ C_{P_L}\ (T_R - T_S)$

Mixing $H_M = 61{,}100\ \text{Btu/hp}\cdot\text{day}\ \ (\text{hp})$

Environmental $H_A = \Sigma\ U_{S_i}\ A_{S_i}\ (T_R - T_A)$

Latent Heat $H_V = \lambda\ Y_{H_2O}\ F_V$

Sensible Heat $H_G = \Sigma\ C_{P_i}\ M_i\ (F_V\ Y_{E_i}\ T_E - F_A\ Y_{A_i}\ T_o)$

Biological $H_B = H_L + H_A + H_V + H_G - H_M$

ASSUMPTIONS

(1) H_M - Assume 90% motor and gearbox efficiency

(2) H_A - Coefficients calculated as per HCC correlations
Ground temperature assume 15°C

(3) H_V - Assume vent flow to feed flow ratio of 0.30 (conservative)

(4) H_G - Assume sensible heat loss in vent gas is negligible

(5) H_V - For weeks where no T_E is available assume
$T_E/T_R = 0.85$ (based on average of previous values)

(6) Vapor Pressure of water in mm Hg is given by:

$$\log VP = 8.13254 - \frac{1764.42}{236.14 + T^\circ C}$$

HEAT LOSS COEFFICIENTS

A) $$\boxed{U_{\text{wall above liquid}}} + \frac{1}{1/h_i + \frac{X_1}{K_1} + \frac{X_2}{K_2} + \ldots + 1/h_o} = 0.037 \text{ Btu/hr-ft}^2\text{-°F}$$

Area = 216.8 ft^2

h_i = surface conductance coefficient = 1.6 Btu/hr ft^2 °F

X_1 = 12" K_1 = 5.0 Btu/hr ft^2/in °F for concrete

X_2 = 3" K_2 = 0.13 Btu/hr ft^2/in °F for urethane foam insulation

h_o = air/surface conductance outside tank = 6.0 Btu/hr ft^2 °F

B) $$\boxed{U_{\text{wall below liquid}}} = 0.039 \text{ Btu/hr-ft}^2\text{-°F}$$

Area = 722.6 ft^2

same as before except $1/h_i = 0$ since liquid touches the wall of the tank.

C) U_{roof}

$$\underset{\text{deck}}{(11.5)^2 \pi/4} - \underset{\text{skid}}{(11.5)\ (4')} = \underset{\text{concrete area}}{58 \text{ ft}^2}$$

$$\boxed{U_{roof}} = \frac{1}{1/h_i + 1/K_a + \frac{X_1}{K_1} + 1/h_o} = 0.303 \text{ Btu/hr-ft}^2\text{-°F}$$

Area = 58 ft^2

h_i = surface conductance inside the tank = 1.6 Btu/hr ft^2 °F

K_a = coefficient of conductance for gas = 1.1 Btu/hr ft^2 °F

X_1 = 8" K_1 = 5.0 for concrete (Btu/hr-ft^2/in-°F)

h_o = air/surface conductance outside tank = 6.0 Btu/hr ft^2 °F

(assumes 15 mph wind)

$\boxed{U_{skid}}$ = same form as for roof = .56 Btu/hr-ft^2-°F

Area = 46 ft^2

h_i = 1.5 Btu/hr ft^2 °F (still air and steel)

h_o = 5.0 Btu/hr ft^2 °F (convertive transfer between skid and 15 mph air)

K_a = 1.1 Btu/hr ft^2 °F (same as above)

X_1 = .75" K_1 = 312 Btu/hr ft^2/in °F for mild steel

D) $$\boxed{U_{floor}} = \frac{1}{\frac{X_1}{K_1} + \frac{X_2}{K_2} + 1/h_o} = 0.092$$

Area = 103.0 ft^2

X_1 = 120" K_1 = 16 Btu/hr ft^2/in °F for wet earth

X_2 = 12" K_2 = 5.0 Btu/hr ft^2/in °F for concrete

h_o = 1.0 Btu/hr ft^2 °F

HEAT BALANCE DATA

Week Beginning	GPD	$\%VS_R$	Lbs $VS_{R/d}$	Power kW	Qg cfm	YO_2 %	T_R °C	T_A °C	T_E °C	T_S °C	$\%VS_{in}$
06-16	16078	23.1	870.4	18	19.9	63.5	50.9	20.0	42.2	19.5	2.81
06-23	15769	24.4	920.1	17.4	14.5	49.8	56.7	25.2	46.4	22.1	2.87
06-30	13333	23.8	722.5	19	17.5	62.8	53.7	25.9	44.8	23.1	2.73
07-07	13443	17.8	515.9	17.8	16.9	61.9	52.6	25.1	44.1	23.6	2.59
07-14	15185	19.8	634.4	19.8	15.9	44.4	52.1	28.8	43.5	24.9	2.53
07-21	18851	20.6	787.0	20.1	18.9	61.2	51.3	26.5	43.7	26.2	2.43
07-28	13782	35.5	1044.6	19.4	18.0	69.2	53.8	27.2	46.7	25.7	2.56
08-04	17263	15.1	476.1	9.58	27.3	80.2	46.5	27.4	41.2	26.8	2.19
08-11	9647	30.5	490.8	10.54	27.8	86.6	45.8	24.0	41.6	25.5	2.00
08-18	9820	23.7	361.0	11.26	22.1	82.4	47.2	22.3	42.3	24.8	1.86
08-25	10314	38.3	817.0	12.17	19.8	67.9	50.3	26.0	41.7	25.1	2.48
09-01	16735	26.9	852.3	13.56	17.0	68.4	47.6	25.5	41.6	25.7	2.27
09-08	17083	38.5	1497.5	16.6	19.8	58.4	47.8	22.0	38.7	26.1	2.73
09-15	12148	21.9	548.0	15.6	23.8	73.9	51.0	23.0	42.1	25.5	2.47
09-22	10061	24.1	453.0	17.36	18.4	80.2	47.0	20.1		24.8	2.24
09-29	10123	30.6	573.5	17.61	21.1	82.1	49.4	14.7		22.8	2.22
10-06	10649	50.6	1110.0	18.37	17.4	73.2	51.3	13.7		21.6	2.47
10-13	15185	20.3	696.7	18.44	17.4	60.4	51.3	13.6		20.9	2.71
10-20	7354	26.5	362.4	18.06	17.4	77.1	52.3	10		19.4	2.23
10-27	7289	28.3	388.8	17.7	13.6	69.3	52.3	7.5		17.3	2.26

Week	H_L Btu/Day	H_M Btu/Day	H_A Btu/hr H_A wall AL	H_A wall BL	H_A roof	H_A skid	H_A floor
06-16	7.579×10^6	1.328×10^6	446.2	1567.5	977.5	1438.1	617.7
06-23	8.191	1.283	454.8	1597.9	996.5	1466.8	717.5
06-30	6.125	1.401	401.4	1410.2	879.4	1294.6	665.9
07-07	5.852	1.312	397.1	1395.0	869.9	1280.5	646.9
07-14	6.200	1.4595	336.4	1181.9	737.1	1085.0	638.3
07-21	7.103	1.482	358.1	1258.0	784.5	1154.8	624.6
07-28	5.814	1.430	384.1	1349.3	841.4	1238.7	667.6
08-04	5.105	0.7062	275.8	968.9	604.2	889.5	542.0
08-11	2.94	0.7769	314.8	1105.8	689.6	1015.2	529.9
08-18	3.302	0.830	359.5	1263.1	787.7	1159.4	554.0
08-25	3.902	0.8971	350.9	1232.7	768.7	1131.6	607.4
09-01	5.502	0.9996	319.1	1121.1	699.1	1029.1	560.9
09-08	5.565	1.224	372.5	1308.7	816.1	1201.4	564.4
09-15	4.650	1.15	404.3	1420.3	885.7	1303.9	619.4
09-22	3.353	1.28	388.4	1364.5	850.9	1252.6	550.6
09-29	4.042	1.298	501.0	1760.2	1097.7	1615.8	591.9
10-06	4.748	1.354	542.9	1907.3	1189.4	1750.9	624.6
10-13	6.930	1.359	544.4	1912.4	1192.6	1755.5	648.7
10-20	3.632	1.331	610.8	2145.7	1338.1	1969.8	641.8
10-27	3.830	1.305	646.9	2272.6	1417.2	2086.2	641.8

Week	ΣH_A Btu/Day	F_V Lb Moles/Day	YH_2O	H_V Btu/Day	H_G Btu/Day	H_B Btu/Day	ΔH_R Btu/Lb VS_R
06-16	1.21×10^5	22.3	.082	3.357×10^4	--	6.401×10^6	7355
06-23	1.26	16.2	.102	3.034	--	7.050	7662
06-30	1.12	19.6	.094	3.383	--	4.864	6733
07-07	1.10	18.9	.090	3.123	--	4.676	9047
07-14	0.95	17.8	.088	2.876	--	4.861	7662
07-21	1.00	21.1	.088	3.409	--	5.751	7307
07-28	1.08	20.1	.103	3.801	--	4.525	4332
08-04	0.79	30.5	.0776	4.345	--	4.518	9489
08-11	0.88	31.1	.0792	4.52	--	2.292	4670
08-18	0.99	24.7	.0822	3.73	--	2.604	7213
08-25	0.98	22.1	.0797	3.23	--	3.131	3832
09-01	0.89	19.0	.0792	2.76	--	4.616	5415
09-08	1.02	22.1	.0679	2.76	--	4.466	2983
09-15	1.11	26.6	.0813	3.97	--	3.646	6653
09-22	1.06	20.6	.0744	2.81	--	2.202	4861
09-29	1.34	23.6	.0809	3.51*	--	2.907	5068
10-06	1.44	19.5	.088	3.15	--	3.548	3196
10-13	1.45	19.5	.088	3.15	--	5.741	8240
10-20	1.61	19.5	.092	3.29	--	2.487	6863
10-27	1.70	15.2	.092	2.57	--	2.712	6976

*From 09-29 on, vent gas temperature is estimated.

TABLE C-1. HAGERSTOWN DAILY AVERAGE TEMPERATURES

Date	°C Sludge Feed	°C Aerobic Reactor	°C Anaerobic Effluent	°C Ambient	°C Aerobic Vent
06-11-80	18.90	20.3	--	12.2	19.25
12	17.67	27.3	--	17.0	21.4
13	18.2	32.3	--	19.9	27.2
14	19.5	34.6	--	21.8	29.0
15	19.6	38.0	--	22.9	32.2
16	19.2	42.0	--	15.1	36.7
17	19.2	44.4	--	19.9	37.7
18	19.3	47.3	--	19.8	36.9
19	19.6	50.6	--	21.3	40.9
20	19.5	54.5	--	21.0	42.7
21	19.6	58.9	--	20.6	48.4
22	19.9	58.5	--	22.0	50.2
23	21.1	57.3	--	24.8	47.7
24	21.2	55.4	37.8	26.8	44.8
25	21.9	53.8	37.8	19.6	47.4
26	21.8	56.2	37.8	24.7	46.5
27	22.4	58.5	37.8	26.5	46.1
28	22.9	57.8	38.9	27.3	46.0
29	23.1	58.0	40.0	26.5	45.6
30	22.7	53.0	40.0	23.4	42.7
07-01-80	22.9	50.1	40.6	23.0	38.7
02	23.1	49.1	40.6	27.5	41.0
03	23.1	50.6	41.1	24.8	44.4
04	23.2	55.8	40.6	29.8	47.2
05	23.3	57.1	41.1	27.4	49.6
06	23.5	59.9	41.7	25.2	50.6
07	23.5	58.0	40.6	25.5	49.0
08	23.3	52.2	42.2	19.5	43.2
09	23.3	51.1	--	25.2	43.8
10	23.5	52.5	41.4	24.7	46.1
11	23.9	52.7	41.9	28.0	43.0
12	23.5	51.8	41.9	26.8	43.4
13	23.9	50.0	41.7	26.3	40.3
14	23.8	54.0	42.2	25.8	42.5
15	23.5	53.2	42.8	28.6	44.3
16	25.0	52.8	43.3	30.4	45.6
17	25.2	54.3	43.3	29.1	44.5
18	25.4	51.8	43.9	28.6	43.0
19	25.8	48.2	44.4	28.3	41.2
20	25.8	50.2	43.3	30.5	43.8
21	25.8	53.7	43.3	30.1	43.4
22	25.6	52.9	44.4	26.6	43.4
23	26.1	53.2	43.9	25.2	43.5
24	25.9	54.3	43.6	24.0	44.1
25	26.1	45.8	43.9	26.5	40.4
26	--	47.8	43.3	26.0	46.5
27	27.4	51.1	46.7	25.5	44.6
28	25.5	53.6	43.3	25.5	47.5
29	25.3	55.7	43.7	25.8	47.2
30	25.5	49.6	43.9	25.4	41.8
31	25.5	51.1	43.7	27.2	46.1
08-01-80	25.8	54.3	43.3	26.5	45.8
02	25.8	55.0	43.1	29.2	47.5
03	26.4	57.1	42.9	29.7	50.9
04	26.2	50.1	43.2	28.8	42.7
05	26.2	47.0	43.3	28.8	39.6
06	26.4	47.1	43.3	26.4	40.9
07	26.7	47.7	43.2	26.0	43.3
08	26.9	46.1	43.2	28.4	41.7
09	26.8	42.8	42.8	29.9	40.0
10	28.3	44.6	42.8	23.5	40.8
11	26.5	46.0	42.8	26.2	42.8
12	26.4	45.7	42.2	27.1	40.5
13	25.9	43.6	42.2	24.3	38.7
14	26.3	44.3	41.7	25.6	41.0

(continued)

TABLE C-1 (continued)

Date	°C Sludge Feed	°C Aerobic Reactor	°C Anaerobic Effluent	°C Ambient	°C Aerobic Vent
08-15-80	25.1	45.8	41.7	22.7	41.7
16	24.5	47.4	41.4	21.3	43.0
17	24.0	47.7	41.4	20.8	44
18	24.8	48.4	41.4	20.1	45.8
19	26.8	51.9	41.1	22.7	44.3
20	24.4	46.9	41.1	23.6	43.7
21	24.5	44.2	40.6	21.3	40.4
22	24.2	44.8	40.6	21.7	40.2
23	24.6	45.9	40.8	23.1	38.7
24	25.1	48.1	41.1	23.8	43.4
25	24.[illegible]	49.1	41.1	24.2	43.1
26	24.4	48.4	41.1	24.1	40.0
27	25.3	52.7	40.7	23.8	40.7
28	25.5	51.2	40.7	25.3	43.2
29	25.6	50.0	41.4	27.9	40.8
30	25.0	50.8	41.0	28.0	43.6
31	24.9	49.7	41.7	26.4	41.5
09-01-80	24.6	52.4	41.9	28.2	45.8
02	24.8	52.9	42.5	29.2	45.7
03	25.1	47.1	42.8	24.5	39.4
04	25.4	43.1	42.8	25.4	37.6
05	26.2	42.4	42.5	24.7	38.1
06	26.8	46.6	42.2	24.6	41.8
07	26.7	49.1	42.2	22.0	41.3
08	26.2	50.7	42.2	22.6	39.1
09	26.2	48.3	42.2	23.7	38.1
10	26.0	43.9	42.2	21.6	35.9
11	25.0	47.0	42.2	19.4	38.5
12	26.0	48.9	42.2	22.5	39.2
13	26.3	46.5	42.2	24.0	40.0
14	26.8	49.9	42.2	22.1	41.2
15	25.8	56.9	42.8	20.4	46.8
16	24.9	50.9	42.6	20.0	41.40
17	25.6	49.6	42.8	24.9	40.9
18	25.8	48.7	43.3	23.7	40.1
19	25.3	50.5	42.8	21.8	41.4
20	25.4	49.9	42.8	24.2	40.8
21	25.5	50.7	42.8	25.9	41.4
22	25.7	49.2	42.8	27.2	42.6
23	26.7	50.6	42.8	23.8	42.2
24	25.3	52.3	42.2	19.9	
25	24.6	43.8	—	18.1	
26	24.5	44.8	42.2	17.6	
27	23.4	43.3	41.7	14.9	
28	23.5	45.1	42.2	14.4	
29	23.4	47.7	41.7	15.3	
30	23.2	50.1	41.7	18.5	
10-01-80	22.8	50.4	47.1	16.1	
02	22.7	51.0	41.1	17.6	
03	22.5	50.9	41.1	13.6	
04	22.8	48.6	41.1	11.6	
05	22.3	47.3	41.1	10.5	
06	20.7	50.7	40.0	13.9	
07	20.6	50.8	40.0	12.5	
08	21.6	51.2	40.0	13.8	
09	22.2	52.7	40.0	17.0	
10	22.2	51.0	40.6	12.2	
11	22.6	53.2	40.6	15.2	
12	21.6	49.5	41.1	11.3	
13	20.2	50.3	41.1	9.5	
14	19.6	52.1	41.1	8.4	
15	20.3	54.9	41.1	11.9	
16	21.2	57.5	41.7	14.1	
17	22.0	48.0	—	42.2	
18	21.9	47.7	42.2	20.9	
19	21.1	48.9	42.2	16.5	

(continued)

TABLE C-1 (continued)

Date	°C Sludge Feed	°C Aerobic Reactor	°C Anaerobic Effluent	°C Ambient	°C Aerobic Vent
10-20-80	20.3	51.2	41.7	11.0	
21	19.7	52.7	41.1	12.4	
22	20.9	52.2	41.1	12.0	
23	19.0	52.6	41.1	6.8	
24	18.0	53.6	41.1	8.5	
25	19.1	52.8	40.6	10.2	
26	18.5	50.9	40.0	9.2	
27	17.0	52.8	39.4	7.0	
28	17.4	51.6	39.4	9.6	
29	17.2	51.5	39.4	7.2	
30	17.6	52.2	38.9	3.7	
31	17.4	53.9	38.9	6.5	
11-01-80	17.3	51.6	38.9	12.1	
02	16.9	52.4	38.3	6.1	
03	16.2	53.3	37.8	6.4	
04	17.4	53.7	37.8	11.4	
05	17.8	53.4	37.8	8.5	
06	17.7	54.2	37.8	6.3	
07	17.4	53.5	37.8	12.0	
08	18.3	54.7	37.8	15.4	
09	6.2	55.0	37.8	14.9	
10	17.0	53.9	37.8	27.2	
11	16.4	52.5	37.2	3.6	
12	15.7	50.6	36.7	6.8	
13	16.1	49.8	36.7	6.3	
14	16.5	50.4	36.7	10.0	
15	17.4	48.7	34.4	8.8	
16	16.3	48.6		3.3	
17	15.4	45.3		-1.5	
18	14.8	45.0		0.9	
19	13.9	44.5		2.2	
20	14.3	44.7		-1.3	
21	14.0	46.3		1.7	
22	14.4	49.1		4.3	
23	14.6	52.6		4.5	
24	14.3	53.2		5.2	
25	14.6	57.4		6.3	
26	14.8	55.3		1.5	
27	15.1	52.2		0.9	
28	14.3	52.5		3.2	
29	13.8	57.9		4.8	
30	14.4	56.3		4.6	
12-01-80	15.0	57.1		8.5	
02	15.7	54.5		9.1	
03	14.1	52.4		1.7	
04	14.0	54.5		0.7	
05	14.6	51.8		-0.9	
06	14.3	52.9		3.3	
07	15.4	54.7		9.1	
08	15.9	53.7		15.4	
09	16.3	53.3		13.2	
10	15.7	53.1		7.2	
11	15.4	54.6		4.5	
12	14.8	52.5		2.6	
13	14.8	52.6		7.1	
14	14.1	55.7		2.8	
15	14.3	55.2		-3.5	
16	14.3	54.1		0.5	
17	13.8	52.6		-2.0	
18	13.7	54.3		0.5	
19	14.3	52.6		2.0	
20	12.9	52.1		-8.8	
21	12.4	51.1		-8.5	
22	10.4	54.8		-7.8	
23	12.2	54.8		-3.5	
24	12.4	53.6		1.9	

(continued)

TABLE C-1 (continued)

Date	°C Sludge Feed	°C Aerobic Reactor	°C Anaerobic Effluent	°C Ambient	°C Aerobic Vent
12-25-80	11.3	53.3		-8.2	
26	10.2	53.9		-9.4	
27	10.0	58.6		3.1	
28	10.1	60.4		1.6	
29	10.4	59.1		1.9	
30	11.5	56.5		2.9	
31	10.2	58.2		-3.3	
01-01-81	9.6	59.5		-2.6	
02	10.0	50.9		-2.0	
03	9.4	52.2		2.5	
04	8.0	53.7		4.6	
05	7.8	56.5		-9.3	
06	7.2	56.3		-8.8	
07	8.3	56.8		-1.5	
08	7.4	55.7		-9.6	
09	8.9	54.1		-7.4	
10	8.8	53.4		-2.7	
11	9.1	54.8		-10.0	
12	8.9	55.4		-11.3	
13	8.5	55		-11.1	
14	9.6	55.2		-6.9	
15	9.4	55.5		-2.2	
16	10.6	55.2		-0.7	
17	9.6	53.0		-5.7	
18	8.9	54.2		-4.0	
19	9.5	55.6		3.3	
20	10.7	56.0		5.4	
21	10.0	54.5		2.5	

TABLE C-2 HAGERSTOWN DDS — SOLIDS DATA

Week	Date	Aerobic Feed TS	Aerobic Feed VS	Aerobic Reactor TS	Aerobic Reactor VS	Aerobic Effluent TS	Aerobic Effluent VS	Anaerobic Effluent TS	Anaerobic Effluent VS	Feed Rate GPH
	06-12-80	3.52	2.83	1.56	1.22	1.72	1.39	—	—	—
	13	3.27	2.61	2.58	2.06	—	—	—	—	677.3
	14	3.23	2.62	2.62	2.10	1.98	1.56	—	—	217.7
	15	3.58	2.89	2.62	2.09	2.42	1.88	—	—	667
1	16	3.53	2.80	2.64	2.08	3.41	2.81	—	—	678.4
	17	3.52	2.80	2.52	1.95	2.52	1.97	—	—	671.1
	18	3.29	2.59	2.70	2.10	2.71	2.10	—	—	680.7
	19	3.55	2.82	2.74	2.13	2.43	1.86	2.35	1.76	667
	20	3.87	3.07	2.78	2.16	2.83	2.16	2.23	1.67	667
	21	3.50	2.80	2.70	2.11	2.78	2.08	2.26	1.66	667
2	23	3.65	2.97	4.85	4.17	2.85	2.15	2.19	1.60	669
	24	3.91	3.15	3.20	2.57	2.88	2.23	2.13	—	674
	25	3.19	2.54	2.73	2.13	2.86	2.23	2.23	1.63	679
	26	2.74	2.20	2.88	2.30	2.87	2.17	2.23	1.63	673.5
	27	3.66	2.96	2.96	2.34	2.84	2.10	2.37	1.77	530.5
	28	3.72	2.97	2.78	2.16	2.74	2.09	2.14	1.81	673
	29	4.11	3.33	2.83	2.24	2.85	2.21	2.25	1.86	724.8
3	30	3.45	2.79	2.82	2.24	2.84	2.21	2.17	1.60	556
	07-01-80	3.49	2.76	2.84	2.55	2.84	2.22	2.17	1.58	595.3
	02	3.21	2.61	2.74	2.21	2.76	2.15	2.05	1.53	675
	03	3.05	2.48	2.56	2.06	2.65	2.08	2.05	1.53	616
	04	3.27	2.55	2.35	1.81	2.36	1.79	2.59	1.88	617
	05	3.74	2.94	2.59	2.02	2.63	2.00	1.91	1.40	462
	06	3.77	2.99	2.90	2.31	2.74	2.08	2.05	1.49	385
4	07	3.18	2.50	2.69	2.05	2.72	2.04	2.27	1.67	452
	08	3.02	2.35	2.76	2.13	2.86	2.16	—	—	752.7
	09	3.02	2.35	2.76	2.13	2.86	2.16	—	—	493
	10	3.14	2.43	2.61	2.00	2.70	2.03	2.21	1.60	617
	11	3.47	2.69	2.54	2.97	2.68	2.03	2.36	1.74	78
	12	3.84	2.96	2.83	2.15	2.86	2.15	2.36	1.73	847
	13	3.71	2.88	3.06	2.31	3.08	2.32	2.64	1.91	693
5	14	3.43	2.67	2.93	2.20	3.06	2.23	2.40	1.73	613
	15	3.42	2.59	2.94	2.19	2.97	2.11	2.45	1.77	645.6
	16	3.61	2.78	2.87	2.18	2.80	2.04	2.40	1.76	539.9
	17	3.67	2.82	2.81	2.09	2.81	2.05	2.53	1.81	708.9
	18	3.35	2.56	2.82	2.07	2.77	2.01	2.56	1.83	749.2
	19	2.43	1.85	2.56	1.85	2.56	1.79	2.41	1.41	801.6
	20	3.61	2.47	2.66	1.99	2.70	1.99	2.46	1.74	358.6
6	21	3.43	2.59	2.85	2.12	2.80	2.06	2.39	1.68	736.8
	22	2.79	2.14	2.83	2.09	2.84	2.08	2.63	2.06	616.2
	23	3.71	2.92	2.72	2.09	2.70	2.06	2.58	1.86	770
	24	3.31	2.51	2.44	1.72	2.68	1.99	2.67	2.00	776.7
	25	2.99	2.33	2.52	1.91	2.65	1.94	2.45	1.74	1129.8
	26	2.48	2.09	2.22	1.98	2.37	1.97	2.36	1.87	—
	27	—	—	1.97	1.52	1.91	1.41	2.36	1.67	706
7	28	3.08	2.47	1.67	1.28	1.56	1.18	2.16	1.53	424
	29	3.82	2.97	2.03	1.51	2.10	1.55	—	—	472
	30	3.50	2.84	2.20	1.64	2.33	1.71	2.23	1.51	589.5
	31	2.86	2.22	2.88	2.18	2.35	1.76	2.11	1.43	706
	08-01-80	3.17	2.48	2.42	1.84	2.40	1.80	2.12	1.43	377
	02	3.14	2.44	2.86	2.23	2.83	1.76	2.17	1.47	589
	03	3.27	2.52	2.47	1.88	2.46	1.80	2.05	1.80	854
8	04	2.57	1.97	2.52	1.90	2.42	1.70	2.17	1.88	854
	05	2.78	2.17	2.77	2.18	2.85	2.01	2.05	1.38	610
	06	2.90	2.33	2.42	1.89	2.43	1.86	2.11	1.47	727.2
	07	3.30	2.60	2.52	1.99	2.52	1.93	2.15	1.46	645.6
	08	2.94	2.31	2.55	1.96	2.55	1.94	1.98	1.35	724
	09	2.60	2.06	2.38	1.80	2.41	1.82	2.03	1.38	728.7
	10	2.39	1.91	2.27	1.87	2.23	1.73	2.04	1.42	724
9	11	2.28	1.81	2.06	1.61	1.77	1.37	1.98	1.37	508.4
	12	2.66	2.12	2.06	1.61	1.87	1.43	1.91	1.39	397.8
	13	2.73	2.17	2.18	1.69	2.03	1.56	1.86	1.26	677.8
	14	1.99	1.57	2.14	1.67	1.98	1.51	1.90	1.28	214
	15	2.79	2.28	1.86	1.48	1.91	1.50	2.01	1.36	295
	16	2.58	2.01	1.96	1.51	1.70	1.22	1.78	1.16	421.8
	17	2.47	2.07	1.72	1.41	1.47	1.17	1.86	1.30	304.7
10	18	2.23	1.87	1.63	1.36	1.74	1.41	1.71	1.19	423.7
	19	2.13	1.73	1.98	1.58	1.95	1.51	—	—	—

All solids are expressed as weight percent. (continued)

TABLE C-2 (continued)

		Aerobic Feed		Aerobic Reactor		Aerobic Effluent		Anaerobic Effluent		Feed Rate
Week	Date	TS	VS	TS	VS	TS	VS	TS	VS	GPH
	08-20-80	2.36	1.89	1.84	1.50	1.80	1.41	1.84	1.29	473
	21	2.41	1.95	1.87	1.50	1.72	1.33	1.89	1.33	353
	22	--	--	--	--	--	--	--	--	424
	23	--	--	--	--	--	--	--	--	231
	24	--	--	--	--	--	--	--	--	545
11	25	2.96	2.40	1.88	1.48	1.83	1.43	--	--	226
	26	3.07	2.45	2.22	1.75	2.10	1.64	1.66	1.11	403
	27	3.13	2.54	2.15	1.70	2.05	1.60	1.50	1.01	494
	28	3.48	2.82	2.29	1.81	2.10	1.64	1.65	1.12	404
	29	2.71	2.20	2.56	2.11	1.94	1.50	1.49	1.02	424
	30	2.84	2.39	--	--	1.78	1.43	1.43	1.04	539
	31	3.03	2.56	2.02	1.67	1.81	1.45	1.50	1.08	516
12	09-01-80	2.73	2.30	2.07	1.70	2.12	1.70	1.40	1.02	635
	02	3.24	2.68	2.03	1.61	2.08	1.65	1.40	0.98	565
	03	2.48	1.92	2.20	1.76	2.79	2.21	1.52	1.06	802
	04	3.00	2.49	2.37	1.97	2.32	1.86	1.49	1.09	970.6
	05	1.50	1.23	2.35	1.92	2.26	1.80	1.76	1.26	956.9
	06	3.36	2.82	1.99	1.65	1.51	1.21	1.45	1.01	443.2
	07	2.91	2.48	1.76	1.46	1.54	1.21	1.54	1.12	515.8
13	08	3.21	2.69	1.97	1.60	1.85	1.46	1.45	1.04	597
	09	3.15	2.56	2.39	1.95	2.23	0.78	1.54	1.15	708.5
	10	3.39	2.73	2.60	2.06	2.43	1.91	1.39	1.97	762.6
	11	2.81	2.37	2.42	1.99	2.47	2.00	1.70	1.23	786
	12	3.25	2.66	2.31	1.88	2.32	1.87	1.59	1.15	481.6
	13	3.78	3.11	3.12	2.54	2.55	2.05	1.62	1.18	627
	14	3.68	3.02	2.79	2.27	2.83	--	1.50	1.09	1030.9
14	15	3.52	2.88	2.96	2.38	2.96	2.37	1.50	1.06	--
	16	3.03	2.51	2.56	2.09	2.51	2.07	1.70	1.31	424
	17	--	--	--	--	--	--	--	--	403
	18	3.06	--	2.34	--	2.16	--	--	--	452
	19	3.27	2.61	3.11	2.67	2.06	1.65	1.67	1.22	527.2
	20	2.50	2.04	2.24	1.91	2.12	1.72	1.47	1.10	616.3
	21	2.74	2.30	2.58	2.19	2.28	1.84	1.75	1.31	616
15	22	2.41	1.96	2.31	1.90	2.32	1.82	2.73	1.24	539.2
	23	2.45	2.03	2.16	1.77	2.21	1.74	1.72	1.43	451.9
	24	2.24	1.80	2.11	1.72	2.31	1.82	1.62	1.19	0
	25	2.31	1.89	1.77	1.43	2.00	1.56	1.71	1.24	360.5
	26	3.06	2.47	1.96	1.60	1.98	1.59	2.03	1.51	496
	27	3.52	2.80	1.90	1.56	2.11	1.68	1.72	1.24	585.4
	28	3.42	2.72	1.58	1.31	2.15	1.72	2.27	1.52	508.4
16	29	3.23	2.52	2.25	1.75	2.20	1.70	1.65	1.17	633.1
	30	2.84	2.25	2.52	2.00	2.34	1.78	1.64	1.18	516
	10-01-80	3.02	2.42	--	--	2.22	1.68	1.71	1.23	385
	02	2.71	2.18	--	--	2.10	1.60	1.69	1.22	385
	03	2.57	2.05	--	--	2.01	1.53	1.64	1.17	423.6
	04	2.38	1.98	--	--	1.72	1.31	1.69	1.25	385
	05	2.54	2.15	--	--	1.47	1.18	1.64	1.26	231
17	06	2.45	1.94	--	--	0.42	0.30	1.73	1.24	154.1
	07	2.17	1.76	1.51	1.20	1.05	0.83	1.60	1.18	250.5
	08	3.06	2.41	1.96	1.61	1.61	1.20	1.83	1.31	183.6
	09	3.83	3.11	1.72	1.39	1.41	1.11	1.31	1.15	353
	10	3.33	2.68	2.37	1.86	1.83	1.21	1.81	1.31	776.7
	11	3.57	2.83	2.55	1.98	2.69	2.02	1.67	1.20	539
	12	3.24	2.59	2.68	2.08	2.44	1.86	1.63	1.16	847
18	13	2.96	2.37	2.50	1.98	3.72	2.10	1.68	1.21	462
	14	3.78	3.05	2.94	2.08	2.33	1.80	1.66	1.20	462
	15	3.77	2.97	2.73	1.98	2.76	2.10	1.72	1.22	693
	16	4.00	3.20	--	--	2.92	2.23	1.72	1.25	602.5
	17	3.63	2.91	--	--	3.13	2.42	1.91	1.40	945.8
	18	2.95	2.38	--	--	2.32	1.80	1.96	1.45	806
	19	2.67	2.11	--	--	2.18	1.65	1.80	1.25	462
19	20	2.69	2.14	--	--	2.21	1.68	2.07	1.50	385
	21	2.72	2.19	--	--	2.18	1.67	2.01	1.45	282.4
	22	2.76	2.17	2.15	1.65	2.17	1.59	2.42	1.57	231
	23	2.68	2.17	2.03	1.59	2.07	1.58	1.89	1.38	424
	24	2.72	2.16	2.49	2.02	2.12	1.63	2.35	1.51	152.3
	25	2.98	2.42	2.12	1.75	2.24	1.75	1.97	1.51	282

(continued)

All solids are expressed as weight percent.

TABLE C-2 (continued)

Week	Date	Aerobic Feed TS	Aerobic Feed VS	Aerobic Reactor TS	Aerobic Reactor VS	Aerobic Effluent TS	Aerobic Effluent VS	Anaerobic Effluent TS	Anaerobic Effluent VS	Feed Rate GPH
	10-26-80	3.02	2.39	2.03	1.55	2.11	1.59	1.83	1.29	385
20	27	3.60	2.88	2.51	2.06	2.11	1.60	2.00	1.43	308
	28	2.79	2.29	2.19	1.80	2.06	1.60	1.87	1.38	353
	29	2.67	2.13	2,13	1.69	2,07	1.57	1.78	1.25	212
	30	2.73	2.19	2.08	1.68	2.10	1.62	1.75	1.26	376.6
	31	2.65	2.06	2.08	1.60	2.09	1.66	1.97	1.35	308
	11-01-80	2.43	1.92	2.01	1.62	2.14	1.65	—	—	282
	02	2.95	2.33	2.10	1.70	2.12	1.63	1.86	1.36	282
21	03	3.36	2.67	2.32	1.85	2.3	1.74	2.12	1.49	359.7
	04	3.49	2.76	2.30	1.79	2.29	1.73	1.86	1.34	424
	05	3.55	2.80	2.33	1.84	2.41	1.83	1.90	1.38	385
	06	3.53	2.86	2.48	1.95	2.56	1.99	1.85	1.38	565
	07	2.98	2.38	2.53	1.95	2.61	1.98	2.00	1.42	462
	08	2.96	2.41	2.33	1.87	2.50	1.94	1.94	1.43	212
	09	3.10	2.60	2.11	1.73	2.19	1.74	1.97	1.43	-
22	10	3.50	2.84	2.26	1.82	2.24	1.73	1.79	1.33	494
	11	3.02	2.56	2.07	1.75	2.24	1.80	2.13	1.68	308
	12	3.13	2.50	2.66	1.75	2.27	1.73	1.95	1.35	282
	13	2.89	2.30	2.31	1.80	2.35	1.78	1.79	1.27	635
	14	2.95	2.37	2.36	1.84	2.19	1.68	1.87	1.33	308
	15	2.86	2.20	2.11	1.65	2.18	1.68	—	—	-
	16	—	—	—	—	—	—	—	—	-
23	17	—	—			—	—	—	—	-
	18	2.68	2.17			1.90	1.46	—	—	-
	19	3.40	2.73			1.85	1.41	—	—	-
	20	2.59	2.07			—	—	—	—	-
	21	2.94	2.40			—	—	—	—	-
	22	3.36	2.84			—	—	—	—	-
	23	3.66	3.15			1.65	1.31	—	—	-
24	24	3.82	3.20			—	—	—	—	573.5
	25	3.75	3.19			2.48	1.97	—	—	676.3
	26	3.56	2.96			—	—	—	—	514.3
	27	3.89	3.21			—	—	—	—	955.7
	28	3.98	3.31			—	—	—	—	707.5
	29	3.83	3.18			—	—	—	—	647.7
	30	3.68	3.09			2.83	2.30	1.62	1.18	586.0
25	12-01-80	3.51	2.88			—	—	—	—	828.7
	02	—	—							968.7
	03									392.7
	04									478
	05									573.5
	06									-
	07									-
26	08									816
	09									937
	10									975.5
	11									1109
	12									1052
	13									956
	14									799
27	15									803
	16									688.5
	17									1071
	18									1530
	19									1185.7
	20									1148
	21									777.7
28	22									1071
	23									994.5
	24									862.7
	25									1879.5
	26									574
	27									1071
	28									841

(continued)

All solids are expressed as weight percent.

TABLE C-2 (continued)

Week	Date	Aerobic Feed		Aerobic Reactor		Aerobic Effluent		Anaerobic Effluent		Feed Rate GPH
		TS	VS	TS	VS	TS	VS	TS	VS	
29	12-29-80									803
	30									692.7
	31									994.5
	01-01-81									994
	02									497.3
	03									1415.5
	04									1684
30	05									1606
	06									1357.5
	07									1645
	08									975
	09									765
	10									879.5
	11									1836
31	12									1529.5
	13									1549
	14									776
	15									684.3
	16									2237
	17									1874
32	18									1951
	19									1412
	20									3518

All solids are expressed in weight percent.

TABLE C-3 HAGERSTOWN DDS DAILY AVERAGE OXYGEN FLOW AND GAS PURITIES

Date	EASTECH Oxygen Feed CFM-NTP	EASTECH Oxygen Feed CFD-NTP	Rotometer ACFM	Aerobic Vent O_2 Flow CFM-NTP	Aerobic Vent	Anaerobic Vent		
					% O_2	% O_2	% CH_4	% CO_2
06-12-80	21.5	30,674	21.2	—	—			
06-13-80	20.6	31,103	21.5	19.6	80.7			
06-14-80	21.1	32,587	23.8	—	78.4			
06-15-80	24.9	31,468	22.8	—	82.0	14	17	—
06-16-80	20.5	32,764	21.0	—	73.7	11.2	15.5	
06-17-80	22.3	34,729	23.0	—	73.2			
06-18-80	22.9	26,993	21.1	—	67.0			
06-19-80	18.1	30,852	21.5	—	63.2			
06-20-80	—	—	19.5	—	54.2			
06-21-80	—	—	18.2	—	56.3			
06-22-80	—	15,124	17.7	—	56.7			
06-23-80	14.5	21,908	17.8	—	61.3			
06-24-80	14.6	16,181	19.0	19.35	72.0			
06-25-80	17.3	21,543	17.5	8.85	66.8			
06-26-80	12.9	—	12.8	—	46.0			
06-27-80	12.2	19,088	13.3	—	34.8	1.5	49.0	
06-28-80	15.0	24,431	15.5	—	31.5	2.0	50.0	
06-29-80	15.3	24,659	16.7	—	36.3	0	51	
06-30-80	17.6	22,857	15.7	—	58.2	2.0	50	
07-01-80	17.1	26,173	17.3	—	52.5	2.5	49.0	
07-02-80	19.5	25,860	19.7	5.43	75.2	1.0	59.0	
07-03-80	18.5	29,419	19.8	—	69.0	1.0	53.0	
07-04-80	18.5	26,191	19.0	7.63	66.3	2.5	56.0	
07-05-80	16.5	23,499	16.8	2.0	61.5	1.8	56.0	
07-06-80	14.5	17,486	11.0	—	57.0	2.0	57.0	
07-07-80	14.7	21,596	13.3	—	53.2	4.0	53.0	
07-08-80	16.9	23,466	16.7	5.29	67.2	—	—	
07-09-80	18.7	24,908	17.0	—	73.3	1.9	48.8	
07-10-80	24.3	25,101	24.3	21.6	75.5	0.5	52.0	
07-11-80	12.2	22,272	16.8	5.1	58.8	1.3	52.0	
07-12-80	16.1	23,076	16.3	6.6	55.5	2.1	52.0	
07-13-80	15.5	22,426	15.0	—	50.1	1.9	49.5	
07-14-80	13.7	19,401	14.2	—	34.7	0.6	51.0	
07-15-80	13.4	20,494	13.5	—	35.0	0.9	52.5	41
07-16-80	16.3	21,995	15.5	—	43.7	—	—	—
07-17-80	14.4	19,810	15.0	—	38.8	1.0	51.0	44.5
07-18-80	15.0	23,770	14.3	—	41.0	.5	45.0	46.0
07-19-80	19.8	27,218	20.5	—	66.3	1.8	44.5	49.5
07-20-80	18.4	27,084	18.2	—	56.2	2.0	42.5	47.3
07-21-80	18.5	26,410	19.0	—	47.5	2.9	40.5	46.0
07-22-80	17.7	24,464	17.8	—	51.3	3.2	37.0	46.0
07-23-80	17.9	27,954	18.7	—	50.5	2.2	37.0	48.0
07-24-80	17.8	23,923	18.0	—	59.8	1.2	35.5	45.8
07-25-80	17.7	—	18.0	—	53.3	1.4	37.0	43.0
07-26-80	23.8	—	23.0	—	83.8	0.5	38.0	43.0
07-27-80	16.8	27,168	19.2	—	82.3	0.2	38.0	45.0
07-28-80	16.8	25,458	19.3	—	62.3	0.4	38.7	44.0
07-29-80	16.6	23,432	16.2	—	63.8	2.4	40.5	43.0
07-30-80	18.5	25,860	16.7	—	74.3	1.2	41.8	41.5
07-31-80	18.6	25,092	19.8	—	72.3	1.65	44.3	37.5
08-01-80	16.9	26,430	18.7	2.67	70.7	1.35	59	36.8
08-02-80	18.8	26,430	19.0	3.51	69.7	1.25	56.0	33.3
08-03-80	18.5	26,877	16.7	—	71.5	1.35	61.5	31.3
08-04-80	18.9	24,090	18.6	10.6	72.9	1.35	62.5	26.0
08-05-80	21.8	35,650	21.7	5.70	79.0	0.6	62.3	27.8
08-06-80	33.4	50,345	31.7	13.6	81.3	0.5	60.8	27.8
08-07-80	33.0	} 86,929	31.7	10.4	79.5	0.85	59.5	27.5
08-08-80	27.3		27.2	8.45	79.8	0.30	59.0	30.0
08-09-80	28.8	42,678	27.3	10.8	81.5	0.25	60.0	31.0
08-10-80	28.0	42,458	28.0	6.3	87.5	0.0	59.0	32.0
08-11-80	30.4	41,766	29.3	7.7	86.8	0.8	54.0	30.0
08-12-80	28.0	40,119	26.8	8.05	85.9	0.50	54.3	30.3
08-13-80	28.2	36,815	26.7	9.2	85.7	1.75	54.0	29.5
08-14-80	26.7	39,191	26.3	19.28	89.0	1.40	52.5	29.0
08-15-80	26.8	34,887	25.0	20.40	87.7	1.75	51.5	29.5
08-16-80	27.8	38,907	28.0	4.24	82.3	1.70	49.5	29.5
08-17-80	26.4	36,470	26.0	2.12	87.7	1.60	48.1	29.9
08-18-80	27.4	35,280	24.2	5.21	86.0	1.50	48.3	28.3
08-19-80	22.8	33,840	23.0	12.10	68.0	2.33	44.7	24.2
08-20-80	24.5	33,527	24.5	11.7	89.0	2.28	45.5	27.3

(continued)

TABLE C-3 (continued)

	EASTECH	EASTECH		Aerobic Vent	Aerobic Vent	Anaerobic Vent		
Date	Oxygen Feed CFM-NTP	Oxygen Feed CFD-NTP	Rotometer ACFM	O_2 Flow CFM-NTP	% O_2	% O_2	% CH_4	% CO_2
08-21-80	16.6	23,403	15.3	—	85.3	0.75	48.3	29.8
08-22-80	16.6	25,159	18.6	—	87.0	2.07	49.0	29.5
08-23-80	16.3	25,985	16.3	—	80.3	1.70	50.7	26.5
08-24-80	19.6	26,801	20.7	—	81.5	3.0	47.2	24.7
08-25-80	20.1	28,697	20.3	—	78.8	3.1	43.8	26.3
08-27-80	22.4	30,204	22.5	21.1	73.5	4.47	45.0	24.8
08-28-80	20.6	26,825	22.8	—	67.3	2.90	45.7	24.2
08-29-80	18.5	26,296	20.5	—	60.5	3.4	43.7	28.2
08-30-80	18.9	21,772	16.8	—	68.2	3.0	44.3	28.8
08-31-80	16.9	21,772	20.2	—	54.8	2.4	45.0	29.3
09-01-80	12.8	24,055	14.5	—	55.1	1.2	45.0	31.2
09-02-80	16.8	22,953	18.5	16.4	73.2	1.27	44.7	29.7
09-03-80	18.4	28,402	18.5	13.7	58.5	2.1	43.0	28.2
09-04-80	22.2	31,015	21.8	24.40	76.5	2.2	43.0	29.0
09-05-80	19.6	26,306	18.7	25.6	87.0	1.4	45.5	31.3
09-06-80	15.5	19,824	15.5	21.1	74.5	1.6	45.0	32.0
09-07-80	13.7	19,396	13.2	10.3	54.3	0.6	46.0	31.5
09-08-80	14.4	21,129	13.8	9.6	48.0	0.7	49.0	32.0
09-09-80	15.3	27,676	15.2	9.70	53.0	1.7	47.5	31.0
09-10-80	17.9	28,070	18.0	16.9	67.2	1.75	47.5	32.3
09-11-80	18.2	23,949	18.0	18.2	69.7	1.35	47.5	33.0
09-12-80	24.2	37,528	23.6	24.3	71.7	3.25	49.0	33.0
09-13-80	23.6	34,534	24.2	16.5	55.0	1.0	50.0	34.0
09-14-80	25.2	32,018	24.8	15.1	44.0	0.2	52.5	35.3
09-15-80	22.9	—	23.2	16.5	54.3	—	—	—
09-16-80	26.8	37,575	26.2	24.1	72.2	1.6	51.5	26.3
09-17-80	22.6	35,382	24.2	—	81.8	1.0	52.0	27.5
09-18-80	24.8	33,726	24.5	—	78.5	0.0	49.5	25.8
09-19-80	24.7	37,562	24.7	—	80.2	0.0	46.5	26.3
09-20-80	23.0	34,837	22.8	—	79.2	0.0	51.3	34.5
09-21-80	20.0	29,980	19.5	—	71.3	0.0	53.5	36.8
09-22-80	19.1	27,967	19.3	—	77.3	0.5	48.5	34.8
09-23-80	17.2	26,580	17.5	17.5	81.7	0.75	49.0	34.5
09-24-80	18.7	25,551	19.0	15.0	85.2	1.0	—	—
09-25-80	17.0	25,344	16.8	—	83.3			
09-26-80	19.8	26,426	19.3	—	83.5			
09-27-80	19.0	—	18.3	—	78.3			
09-28-80	17.8	—	17.9	—	72.4			
09-29-80	—	—	21.9	—	78.5			
10-01-80	—	—	21.8	—	87.3			
10-02-80	—	—	21.3	—	80.5			
10-03-80	—	—	22.0	—	82.7			
10-04-80	—	—	21.2	—	86.9			
10-05-80	—	—	21.3	—	90.3			
10-06-80	19.9	—	19.5	21.2	91.1			
10-07-80	—	—	10.3	—	85.7			
10-08-80	—	—	12.2	—	79.3			
10-09-80	—	—	15.7	—	62.7			
10-10-80	—	—	20.8	—	61.7			
10-11-80	—	—	22.3	—	62.3			
10-12-80	—	—	20.7	—	69.7			
10-13-80	—	—	20.3	—	77.8			
10-14-80	—	—	18.0	—	59.0			
10-15-80	—	—	16.3	—	47.3			
10-16-80	—	—	18.0	—	35.7			
10-17-80	—	—	16.7	—	64.3			
10-18-80	—	—	17.3	—	67.2			
10-19-80	—	—	15.5	—	71.3			
10-20-80	—	—	17.7	—	73.8			
10-21-80	—	—	17.7	—	77.3			
10-22-80	—	—	17.2	—	74.3			
10-23-80	—	—	18.3	—	78.8			
10-24-80	—	—	16.8	—	78.0			
10-25-80	—	—	17.3	—	80.0			
10-26-80	—	—	16.8	—	77.5			
10-27-80	—	—	14.3	—	77.3			
10-28-80	—	—	14.0	—	72.8			
10-29-80	—	—	15.0	—	74.2			
10-30-80	—	—	14.8	—	71.7			
10-31-80	—	—	13.5	—	69.5			
11-01-80	—	—	11.0	—	66.0			
11-02-80	—	—	12.3	—	53.3			

(continued)

TABLE C-3 (continued)

	EASTECH	EASTECH		Aerobic Vent	Aerobic Vent	Anaerobic Vent		
Date	Oxygen Feed CFM-NTP	Oxygen Feed CFD-NTP	Rotometer ACFM	O_2 Flow CFM-NTP	% O_2	% O_2	% CH_4	% CO_2
11-03-80	--	--	11.5	--	70.0			
04	--	--	12.0	--	64.4			
05	--	--	13.3	--	56.0			
06	--	--	13.0	--	58.7			
07	--	--	13.8	--	65.2			
08	--	--	14.3	--	66.3			
09	--	--	14.8	--	70.8			
10	--	--	15.7	--	76.8			
11	--	--	14.5	--	74.6			
12	--	--	15.0	--	74.5			
13	--	--	16.0	--	71.3			
14	--	--	15.0	--	71.3			
15	--	--	11.7	--	59.2			
16	--	--	11.3	--	66.0			
17	--	--	12.5	--	73.2			
18	--	--	11.7	--	81.0			
19	--	--	14.7	--	84.8			
20	--	--	13.3	--	82.2			
21	--	--	14.8	--	80.5			
22	--	--	15.2	--	68.9			
23	--	--	13.3	--	56.0			
24	--	--	13.0	--	48.3			
25	--	--	12.8	--	38.2			
26	--	--	16.5	--	41.3			
27	--	--	16.8	--	39.3			
28	--	--	16.7	--	37.2			
29	--	--	13.3	--	23.3			
30	--	--	13.0	--	23.5			
12-01-80	--	--	13.0	--	21.8			
02	--	--	13.7	--	33.5			
03	--	--	17.3	--	59.8			
04	--	--	14.3	--	61.8			
05	--	--	14.7	--	41.2			
06	--	--	14.0	--	47.3			
07	--	--	12.2	--	32.3			
08	--	--	13.7	--	25.5			
09	--	--	16.0	--	34.5			
10	--	--	20.0	--	40.3			
11	--	--	19.8	--	37.0			
12	--	--	18.7	--	32.8			
13	--	--	15.5	--	28.7			
14	--	--	14.8	--	24.5			
15	--	--	17.7	--	30.5			
16	--	--	16.5	--	26.3			
17	--	--	16.2	--	29.3			
18	--	--	16.2	--	27.5			
19	--	--	17.7	--	28.2			
20	--	--	15.8	--	42.7			
21	--	--	14.7	--	43.3			
22	--	--	14.2	--	53.3			
23	--	--	14.2	--	43.0			
24	--	--	16.5	--	35.5			
25	--	--	17.7	--	43.7			
26	--	--	16.8	--	39.7			
27	--	--	14.3	--	54.7			
28	--	--	11.8	--	62.0			
29	--	--	10.3	--	53.7			
30	--	--	10.8	--	38.5			
31	--	--	11.3	--	52.8			
01-01-81	--	--	11.8	--	58.8			
02	--	--	11.5	--	53.2			
03	--	--	13.0	--	50.8			
04	--	--	14.0	--	34.7			
05	--	--	15.8	--	51.0			
06	--	--	20.3	--	72.7			
07	--	--	17.3	--	70.2			

(continued)

TABLE C-3 (continued)

	EASTECH	EASTECH		Aerobic Vent	Aerobic Vent	Anaerobic Vent		
Date	Oxygen Feed CFM-NTP	Oxygen Feed CFD-NTP	Rotometer ACFM	O_2 Flow CFM-NTP	% O_2	% O_2	% CH_4	% CO_2
01-08-81	—	—	22.0	—	77.5			
09	—	—	21.7	—	70.0			
10	—	—	26.2	—	—			
11	—	—	22.2	—	—			
12	—	—	19.8	—	—			
13	—	—	20.2	—	—			
14	—	—	21.0	—	—			
15	—	—	19.7	—	—			
16	—	—	19.7	—	—			
17	—	—	18.2	—	—			
18	—	—	13.8	—	—			
19	—	—	15.2	—	—			
20	—	—	13.8	—	—			
21	—	—	13.5	—	—			

TABLE C-4 HAGERSTOWN D.D.S. AVERAGE POWER AND RPM

Date	RPM	Kilowatt (Permanent)	Kilowatt (Recording)
06-11-80	32.0	16.4	--
06-12-80	32.2		
06-13-80	32.2	14.1	13.0
06-14-80	32.3	16.8	15.8
06-15-80	32.3	17.6	16.4
06-16-80	32.1	18.7	17.4
06-17-80	32.1	19.3	18.1
06-18-80	32.0	19.63	18.6
06-19-80	32.1	18.5	17.3
06-20-80	32.0	19.3	18.2
06-21-80	32.1	19.3	18.2
06-22-80	32.1	19.2	18.4
06-23-80	32.0	17.8	16.4
06-24-80	32.1	17.3	16.5
06-25-80	32.2	16.2	17.0
06-26-80	32.0	18.7	17.5
06-27-80	32.0	18.8	17.7
06-28-80	32.1	19.4	17.9
06-29-80	32.1	19.8	18.5
06-30-80	32.0	20.3	19.1
07-01-80	32.0	20.9	19.6
07-02-80	32.0	20.7	19.6
07-03-80	31.9	20.5	19.25
07-04-80	32.0	19.9	18.75
07-05-80	32.0	19.7	18.5
07-06-80	32.0	19.8	18.4
07-07-80	32.1	19.0	18.0
07-08-80	32.1		18.8
07-09-80	32.1		18.3
07-10-80	32.1		16.7
07-11-80	32.1		16.3
07-12-80	32.1		17.4
07-13-80	32.0		18.8
07-14-80	32.1		18.7
07-15-80	32.3		19.3
07-16-80	32.0		19.8
07-17-80	32.0		20.2
07-18-80	32.0		20.3
07-19-80	32.3		19.9
07-20-80	32.2		20.1
07-21-80	32.1		20.1
07-22-80	32.2		20.0
07-23-80	32.2		20.5
07-24-80	32.2		20.4
07-25-80	32.2		20.4
07-26-80	32.0		19.8
07-27-80	32.3		19.25
07-28-80	32.2		19.5
07-29-80	32.1		19.17
07-30-80	32.1		19.33
07-31-80	32.0		19.38
08-01-80	32.2		-
08-02-80	32.05		-
08-03-80	32.1		-
08-04-80*	32.4		19.0
08-04-80*	24.2		7.33
08-05-80	24.3		7.77
08-06-80	24.5		7.67
08-07-80	24.1		7.75
08-08-80	24.2		8.58
08-09-80	24.2		9.25
08-10-80	24.1		9.25
08-11-80	24.2		9.0
08-12-80	24.1		9.29
08-13-80	24.2		9.58
08-14-80*	24.3		9.25
08-14-80*	28.5		12.3
08-15-80	28.7		11.5
08-16-80	28.8		11.7
08-17-80	28.6		11.7
08-18-80	28.69		11.5
08-19-80	28.50		11.6
08-20-80	28.6		11.9
08-21-80	28.9		10.8
08-22-80	28.7		10.6
08-23-80	28.6		11.5
08-24-80	28.7		11.0
08-25-80	28.9		11.5
08-26-80	28.4		12.0
08-27-80	28.5		12.3
08-28-80	28.6		12.3
08-29-80	28.6		12.4
08-30-80	28.5		12.3
08-31-80	28.5		12.3
09-01-80	28.5		12.7
09-02-80	28.5		12.7
09-03-80	28.5		13.7
09-04-80	28.5		14.2

(continued)

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TABLE C-4 (continued)

Date	RPM	Kilowatt (Permanent)	Kilowatt (Recording)
09-05-80	28.2		14.0
09-06-80	26.4		13.8
09-07-80	28.4		13.8
09-08-80	28.5		15.0
09-09-80	28.4		14.3
09-10-80	28.5		14.8
09-11-80*	28.6		14.75
09-11-80*	32.0		18.5
09-12-80	32.1		18.3
09-13-80	32.0		19.25
09-14-80	32.0		18.9
09-15-80	32.1		15.5
09-16-80	32.2		12.8
09-17-80	32.2		14.2
09-18-80	32.3		16.8
09-19-80	32.3		16.8
09-20-80	32.5	17.7	16.7
09-21-80	32.3	17.5	16.6
09-22-80	32.4	17.3	16.3
09-23-80	32.2	17.1	16.0
09-24-80	32.0	17.1	
09-25-80	32.2	17.2	
09-26-80	32.2	17.6	
09-27-80	32.2	17.8	
09-28-80	32.3	17.8	
09-29-80	32.0	17.9	
09-30-80	32.1	17.5	
10-01-80	32.1	17.5	
10-02-80	32.8	17.5	
10-30-80	32.5	17.3	
10-04-80	32.0	17.4	
10-05-80	32.2	18.0	
10-06-80	32.2	18.2	
10-07-80	32.0	18.0	
10-08-80	32.2	18.0	
10-09-80	32.2	17.8	
10-10-80	32.2	18.8	
10-11-80	32	18.6	
10-12-80	32.1	18.9	
10-13-80	32.3	17.5	
10-14-80	32.4	18.0	
10-15-80	32.2	18.0	
10-16-80	32.2	18.5	
10-17-80	32.2	19.0	
10-18-80	32.0	19.2	
10-19-80	32.2	18.9	
10-20-80	32.3	18.9	
10-21-80	32.0	18.2	
10-22-80	32.3	18.0	
10-23-80	32.2	18.0	
10-24-80	32.5	18.0	
10-25-80	32.0	17.9	
10-26-80	32.1	18.0	
10-27-80	32.3	18.2	
10-28-80	32.2	18.0	
10-29-80	32.5	17.7	
10-30-80	32.5	17.7	
10-31-80	32.3	17.3	
11-01-80	32.1	17.55	
11-02-80	32.0	17.50	
11-03-80	32.2	17.8	
11-04-80	32.3	18.1	
11-05-80	32.2	18.5	
11-06-80	32.6	18.5	
11-07-80	32.2	18.3	
11-08-80	32.7	18.5	
11-09-80	32.2	18.3	
11-10-80	32.1	18.2	
11-11-80*	32.2	18.3	
11-11-80*	28.6	12.9	
11-12-80	28.3	13.0	
11-13-80	28.5	13.0	
11-14-80	28.5	12.8	
11-15-80	28.5	13.4	
11-16-80	28.4	13.1	
11-17-80	28.5	13.2	
11-18-80	28.7	12.5	
11-19-80	28.5	13.0	
11-20-80	28.7	13.0	
11-21-80	28.6	13.2	
11-22-80	28.0	13.6	
11-23-80	28.0	13.6	
11-24-80	28.6	14.0	
11-25-80	28.3	14.8	
11-26-80	28.9	15.0	
11-27-80	28.5	15.5	
11-28-80	28.5	15.5	
11-29-80	28.4	15.0	
11-30-80	28.6	15.0	

(continued)

TABLE C-4 (continued)

Date	RPM	Kilowatt (Permanent)	Kilowatt (Recording)
12-01-80	28.5	15.0	
12-02-80	28.3	15.0	
12-03-80	28.6	14.8	
12-04-80	28.6	14.5	
12-05-80	28.4	14.5	
12-06-80	28.6	14.5	
12-07-80	28.3	14.7	
12-08-80	28.5	14.7	
12-09-80	28.5	14.8	
12-10-80	28.7	14.5	
12-11-80	28.5	14.7	
12-12-80	28.2	15.2	
12-13-80	28.4	15.3	
12-14-80	28.3	15.3	
12-15-80	28.4	15.3	
12-16-80	28.2	15.5	
12-17-80	27.5	15.7	
12-18-80	28.2	15.5	
12-19-80	28.4	15.3	
12-20-80	28.6	15.0	
12-21-80	28.5	15.0	
12-22-80	28.5	15.0	
12-23-80	28.7	15.0	
12-24-80	28.4	15.0	
12-25-80	28.4	15.0	
12-26-80	28.4	15.0	
12-27-80	28.4	14.9	
12-28-80	28.3	14.9	
12-29-80	28.6	15.0	
12-30-80	28.6	15.0	
12-31-80	28.6	14.7	
01-01-81	28.6	14.3	
01-02-81	28.6	14.7	
01-03-81	28.5	15.0	
01-04-81	28.4	14.9	
01-05-81	28.6	14.5	
01-06-81	28.6	14.5	
01-07-81	28.7	14.8	
01-08-81	28.4	14.7	
01-09-81	28.5	14.8	
01-10-81	28.5	15.0	
01-11-81	28.5	15.1	
01-12-81	28.5	15.0	
01-13-81	28.3	15.0	
01-14-81	28.6	15.0	
01-15-81	28.5	14.8	
01-16-81	28.3	14.7	
01-17-81	28.5	14.4	
01-18-81	28.5	14.2	
01-19-81	28.5	14.2	
01-20-81	28.7	14.3	
01-21-81	28.5	15.0	

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*Changed rpm.

APPENDIX D

HAGERSTOWN BDS ANALYTICAL RESULTS

	SLUDGE FEED									AEROBIC								ANAEROBIC		
Date	pH	Alkalinity mg/l as $CaCO_3$	COD g/kg wet	COD g/kg dry	TKN mg/kg wet	NH_3 mg/kg wet	TP mg/kg wet	OP mg/kg wet	Mixed Liquor pH	Eff. pH	Alkalinity mg/l as $CaCO_3$	COD g/kg wet	COD g/kg dry	TKN mg/kg wet	NH_3 mg/kg wet	TP mg/kg wet	OP mg/kg wet	Eff. pH	Alkalinity mg/l as $CaCO_3$	Volatile Acids mg/l
06-12-80	5.7									6.35										
13	5.7								6.1											
14	5.8									6.6										
15	5.9									6.6										
16	6.2									6.7										
17	5.8									6.8										
18	6.3									7.1										
19	5.9									7.2								7.0		
20	5.95									7.45								7.65		
21	5.95									7.05								7.10		
22																				
23	6.2									7.3								7.20		
24	5.8	880			2034.7	172.7	292.5	202.8	6.9	7.1	3340									
25	5.8		1.98	982.7					7.2	7.2		9.85	936.7					7.2		
26	6.25	730			1891.6	81.1	273.8	183.9	7.1	7.0	2560					298	263.3	7.4	3710	360
27	6.10		2.73	1215.6					7.0	7.1		11.93	1186.4					7.3		
28	6.2								6.9	7.0								7.3		
29	5.8								7.3	7.2								7.5		
30	5.9		2.73	39.5					7.0	7.3		9.41	31.1					7.5		
07-01-80	5.9	920			3059.1	140.1	288.7	212.8	6.8	7.1	2470					275.8	265	7.1	4030	460
02	5.8		2.60	31.2					6.9	7.0		10.0	37.4					7.4		400
03	6.6	860			2128	125.0	323	67	6.8	6.9	1870			2075	457	267	169	7.4	3870	
04	5.75								6.9	7.2								7.4		
05	5.9								7.0	7.3								7.4		
06	5.7								7.0	7.1								7.3		
07	6.0				2294	93.4	316	199	7.1					2408	826	316	269	7.4		
08	6.5	1250	0.65	28.7					6.95	7.1	2300	10.7	28.7					7.4	3880	
09	6.5	1250							6.95	7.1	2300							7.4	3880	480
10	6.9				2486	465.0	304.5	220	7.0	7.1				2388	718	301	291	7.4		
11	6.2	850	2.15	32.7					6.9	7.0	2360	11.7	26.7					7.25	3920	480
12	6.2								6.7	6.9								7.4		
13	6.2								6.9	7.0								7.3		
14	6.0	880	0.65	33.5					6.7	6.8	2110	7.18	27.8					7.3	3690	565
15	5.8				2271	101.9	347	185.9	6.6	7.1				2565	727.5	369.5	320.7	7.2		
16	5.7	590	1.69	34.4					6.95	6.7	3450	6.29	26.7					7.25		665
17	5.8				2081.4	100.4	374.8	203.6	6.80	6.8				2222.2	602.2	330.1	267.3	7.10		
18	5.75	580	2.58	37.3					6.50	6.9	2100	7.62	27.0					7.10	3470	655
19	5.8								7.10	6.9								7.30		
20	5.7								6.6	6.7								6.9		
21	6.3	870	2.13	58.7					6.6	6.8	2060	5.69	34.5					7.0	3350	1190
22	6.2				2018.1	69.3	326.5	196	6.7	7.0				2303.9	615.1	336	308.9	7.0		
23	6.0	870	1.56	33.8					6.7	7.0	2210	4.80	25.2					7.0	3000	1365
24	5.8				2334.1	89.1	309.3	148	6.9	6.8				2239.5	609.9	307.2	249.5	6.9		
25	5.5	560	1.39	33.7	2091.6	88.6			6.7	7.2	2340	4.21	27.1	2789	679.2			6.9	2920	1600
26	6.0								6.6	6.8								6.7		
27									7.1	7.1								6.8		
28	6.0	800	2.13	29.1					7.1	7.2	1740	4.21	14.8					6.7	2900	1495
29	5.9				2803	77.3	318.9	164.3	6.9	7.1				1717	580.2	629	225.8	6.9	3410	1695
30	6.2	820	2.13	36.8					7.6	7.7	2510	7.18	27.2					7.0	3640	1830
31	5.8				2093.7	81.7	313	161	7.4	7.2				2034.9	552.6	292	239	7.1	3490	1695

(continued)

		SLUDGE FEED							AEROBIC									ANAEROBIC		
Date	pH	Alkalinity mg/ℓ as $CaCO_3$	COD g/kg wet	COD g/kg dry	TKN mg/kg wet	NH_3 mg/kg wet	TP mg/kg wet	OP mg/kg wet	Mixed Liquor pH	Eff. pH	Alkalinity mg/ℓ as $CaCO_3$	COD g/kg wet	COD g/kg dry	TKN mg/kg wet	NH_3 mg/kg wet	TP mg/kg wet	OP mg/kg wet	Eff. pH	Alkalinity mg/ℓ as $CaCO_3$	Volatile Acids mg/ℓ
08-01-80	5.9	690	1.24	34.2					6.9	7.1	2380	7.03	25.1					7.1	3480	1555
02	5.7								7.1	7.1								7.2	3540	1220
03	6.0								7.0	7.2								7.3		
04	6.7	820	0.80	29.5					7.1	7.3	2580	6.88	28.4					7.5	4000	870
05	6.0				1907	70.2	407.1	137.6	7.0	6.9				2088	518.3	354.8	264.5	7.4	4080	645
06	6.0	1130	0.8	27.9					6.8	7.0	1740	3.32	24.8					7.5	4100	710
07	5.9				2356.9	42.5	356.5	161.2	7.0	7.0				1997.9	503.7	685.9	238.3	7.4	3780	570
08	5.75	790	1.09	29.9					6.8	7.0	2320	4.06	25.8					7.5	3800	480
09	5.8								6.9	7.0								7.4		
10	6.0								6.7	6.8								7.2		
11	6.1	550	0.95	21.9					6.9	7.3	1740	3.17	16.0					7.6	4070	460
12	6.5				1725	53.9	266.8	78.1	7.2	7.3				1678.5	504.7	249	199.8	7.5		
13	5.9	720	0.65	23.8					6.75	7.1	1690	2.43	17.9					7.5	3610	485
14	6.3				1396.6	46.6	225.5	87.6	6.8	6.8				1679.1	416	242.1	200	7.3	3870	500
15	5.7	590	0.65	29.5					7.0	7.4	1700	2.13	16.3					7.55	4080	415
16	5.7								6.9	7.0								7.5		
17	5.8								7.0	6.7								7.3		
18	5.9	560	1.39	20.6					6.95	7.3	1730	3.47	15.8					7.35	3910	435
19	6.3				1484.3	54.8	245.2	52.6	7.1	7.2				1669.7	433.9	258.9	173.5			
20	6.1	680	0.65	23.8					7.3	7.4	2010	4.21	20.0					7.3	3960	470
21	6.0						284	93	7.0	7.4						280	175	7.3		
22	6.1		0.65	23.3					6.9									7.5	3720	380
23	6.0								6.9	7.1								7.5		
24	5.9								6.9	7.1								7.2		
25	6.1	1260	1.84	30.0					7.1	7.1	1790	3.62	20.3					7.6	3540	
26	6.2					49.2	282	126	7.0	7.3					468	241	221	7.4		
27	6.2	520	0.65	34.1					7.0	7.3	1800	3.62	22.0					7.4	3580	400
28	6.0				2304	67	304	75	7.2	7.6						196	171	7.3		
29	6.0	550	0.65	29.3					7.0	7.8	1650	4.36	19.6					7.5	3600	400
30	6.0								7.4	7.0								7.4		
31	6.0								7.3	7.6								7.3		
09-01-80	6.0								6.8	6.8								7.3		
02	6.1						241.7	93.9	7.4	7.3						202.8	139.2	7.3		
03	6.15	650	0.65	34.5	2346.4	72.6			6.95	6.9	1830	2.87	25.2	2154.6	525.9			7.5	3540	390
04	6.1				2266.1	66.3	214.9	80.1	6.9	7.0				2080.5	514.3	181.8	136.3	7.4		
05	6.7	360	1.24	18.3					6.8	7.0	1370	3.47	25.3					7.4	3190	470
06	6.0								6.9	7.0								7.4		
07																				
08		530	0.65	35.1							1520	2.13	18.8						3470	455
09	6.0		0.95	36.8	2474.3	72.9	120.3	82.3	6.7	6.8		3.62	26.7	2020.5	556.5	163.9	124.6	7.3		
10	6.1	945							6.6	6.8	3616							7.3	3430	460
11	6.1				2039.8	57.1	134.7	40.9	6.8	6.8				1998.7	392.7	138.1	106.4	7.4		
12	6.1	740	0.77	36.1					6.9	6.9	1580	6.56	26.8					7.5	3380	460
13	5.9								7.0	6.9								7.6		
14	5.8								6.6	6.5								7.2		
15	5.9	980	0.92	36.0					6.8	6.8	1900	7.45	31.0					7.4	3310	495
16	5.7					85.0	188	77.1	7.1	7.3					627	143	135	7.4	3550	480
17																				
18	6.1					42.9			6.9	7.0					1151			7.4		
19	6.2		0.92	32.8					7.3	8.0		4.33	23.2					7.4	3360	490
20	6.1								7.0	6.9								7.4		
21	6.1								7.1	7.1								7.3		

(continued)

	SLUDGE FEED								AEROBIC									ANAEROBIC		
Date	pH	Alkalinity mg/ℓ as $CaCO_3$	COD g/kg wet	COD g/kg dry	TKN mg/kg wet	NH_3 mg/kg wet	TP mg/kg wet	OP mg/kg wet	Mixed Liquor pH	Eff. pH	Alkalinity mg/ℓ as $CaCO_3$	COD g/kg wet	COD g/kg dry	TKN mg/kg wet	NH_3 mg/kg wet	TP mg/kg wet	OP mg/kg wet	Eff. pH	Alkalinity mg/ℓ as $CaCO_3$	Volatile Acids mg/ℓ
09-22-80	6.1	420	0.70	27.3					7.6	7.4	1570	7.00	26.0					7.5	3140	475
23	6.0								7.2	7.2								7.4		
24	6.2								7.9	7.0								7.5	3210	350
25	5.9								7.2	7.6								7.5		
26	5.8	410							6.9	6.9	890							7.6	3160	370
27	6.0								6.9	6.9								7.5		
28	5.8								6.7	6.5								7.2		
29	6.0	660							6.7	6.8	1420							7.4	2990	530
30	5.8								6.7	6.8								7.1		
10-01-80	6.1	750								7.2	1970							7.3	3480	505
02	6.0									7.1								7.1		
03	6.2	650								6.9	1960							7.3	3350	495
04	6.0									6.9								7.4		
05	6.2									7.2								7.2		
06	6.1									7.0								7.1	3420	540
07	6.4								7.4	7.4								7.3		
08	5.8	1100							7.3	7.35	1800							7.2	3190	
09	5.7								6.8	7.0								7.2		
10	6.0								7.0	7.1								7.3	3390	425
11	6.1								6.9	7.0								7.4		
12										--										
13	6.0								7.1	7.0								7.4	3360	505
14	6.0								7.3	7.4								7.3		
15	5.7	1150							6.7	6.9	2520							7.3	3400	595
16	5.8									7.0								7.1		
17	6.1	1080								7.2	2760							7.3	3370	625
18	6.0									6.9								7.3		
19	6.1									6.8								7.0		
20	6.1	660								7.1	1790							7.3	3360	540
21	6.2									7.3								7.2		
22	5.7	500							7.2	7.28	2230							7.2	3570	380
23	5.9								7.2	7.3								7.2		
24	6.1	650							7.5	7.7	1910							7.4	3590	385
25	6.1								7.1	7.0								7.4		
26	6.1								7.2	7.4								7.2		
27	5.9	830							7.1	7.3	2050							7.2	3810	285
28	5.8								7.1	7.2								7.2		
29	6.2	660							7.5	7.4	2090							7.4	3580	550
30	5.8								6.9	7.1								7.2		
31	6.4	940							7.2	7.3	2490							7.35	3870	290
11-01-80	6.1								7.0	7.2										
02	6.4								6.9	7.0								7.0		
03	6.4	1130							7.2	7.3	2440							7.3	3540	305
04	6.2	--							6.9	7.1	--							7.0		
05	6.2	1080							7.0	7.0	2530							7.3	3830	305
06	5.5	780							6.6	6.7	2460							7.0	3630	330
07	5.9	--							7.0	7.1	--							7.3	--	--
08	6.0	--							7.1	7.0	--							7.3	--	--
09	6.2	750							7.1	7.1	2600							7.2	3650	325
10	5.9	--							7.2	7.3	--							7.3	--	--
11	6.0	980							7.1	7.2	2400							7.1	3500	--
12	5.8	--							7.1	7.1	--							7.2	--	--
13	5.9	--							7.0	7.1	--							7.2	--	--

(continued)

	SLUDGE FEED								AEROBIC									ANAEROBIC		
Date	pH	Alkalinity mg/ℓ as $CaCO_3$	COD g/kg wet	COD g/kg dry	TKN mg/kg wet	NH_3 mg/kg wet	TP mg/kg wet	OP mg/kg wet	Mixed Liquor pH	Eff. pH	Alkalinity mg/ℓ as $CaCO_3$	COD g/kg wet	COD g/kg dry	TKN mg/kg wet	NH_3 mg/kg wet	TP mg/kg wet	OP mg/kg wet	Eff. pH	Alkalinity mg/ℓ as $CaCO_3$	Volatile Acids mg/ℓ
11-14-80	5.8	600							7.2	7.3	2420							7.3	3690	300
15	5.9	--							7.0	7.1	--							--	--	--
16	6.0	--							7.0	6.9	--							--	--	--
17	6.3	470							7.1	7.1	2370							--	--	--
18	6.2	--							--	7.0	--							--	--	--
19	6.2	--							--	7.3	--							--	--	--
20	6.3	--							--	--	--							--	--	--
21	6.3	--							--	--	--							--	--	--
22	6.2	--							--	--	--							--	--	--
23	5.7	--							--	7.2	--							7.3	--	--
24	5.7	--							--	--	--							7.3	--	--
25	5.6	--							--	7.1	--							7.2	--	265
26	6.2	--							--	--	--							--	--	--
27	5.6	--							--	--	--							--	--	--
28	5.5	--							--	--	--							--	--	--
29	5.8	--							--	--	--							--	--	--
30	5.8	--							--	7.3	--							7.2	3660	365
12-01-80	5.4	--							--	--	--							--	--	--

APPENDIX E

PATHOGEN SAMPLE CONDITIONS

Sample Date	Feed Temp. $^{\circ}$C	Aerobic Temp. $^{\circ}$C	Anaerobic Temp. $^{\circ}$C	Aerobic R.T. Days	Anaerobic R.T. Days	Comments
03-31 04-14	-	-	38	-	20-50	Control samples of existing anaerobic digester effluent
06-16	19.0	40.7		1.01		Process Start-Up
06-30	22.5	53.5	40.0	1.23	10.8	Anaerobic digester on line
07-14	23.4	53.7	42.2	1.11	9.5	
07-21	25.5	52.0	43.3	0.93	7.8	
07-28	25.4	50.5	43.3	1.61	24.8	Sample taken 2½ days after major system upset.
08-04	25.4	50.2	43.2	0.80	11.7	
08-18	23.5	47.5	41.4	1.61	24.8	
09-02	24.2	52.4	42.5	1.21	19.0	New tubing used on aerobic samples. Reactor sample taken before feed cycle while effluent taken after.
09-15	26.0	61.0	42.6	1.61	27.6	Feed stopped 11 hours before sample. Aerobic effluent line purged by dropping liquid level before sampling.

(continued)

Sample Date	Feed Temp. °C	Aerobic Temp. °C	Anaerobic Temp. °C	Aerobic R.T. Days	Anaerobic R.T. Days	Comments
10-06	19.0	51.2	40.0	4.43	59.1	Aerobic effluent sample taken directly by dipping cup into overflow pipe.
10-13	19.0	52.5	41.1	1.48	23.0	Feed stopped for 4 hours. Samples taken after feed cycle restarted.
10-27	16.1	53.9	39.4	2.22	33.3	Sample taken to check for possible recontamination during shipment.*

*On 10-27-80 a sample of aerobic mixed liquor was placed in a glass beaker and heated to 250°F at 16 psig for 15 minutes. The sample was then poured into a sterile sample cup to test for possible recontamination during shipment. The results are labeled SHIPMENT in the pasteurization tables.

APPENDIX F - RAW PATHOGEN DATA

TABLE F-1 TOTAL COLIFORM (MPN/100 ml)

Sample Date	Raw Feed	Aerobic Effluent	Anaerobic Effluent	Aerobic Mixed Liquor	Control Effluent	Shipment
03-31-80	7.8×10^5	--	--	--	9.2×10^7	--
04-14-80	9.2×10^8	--	--	--	9.2×10^6	--
06-16-80	--	--	--	--	--	--
06-30-80	3.3×10^8	3.5×10^7	7.9×10^4	--	--	--
07-14-80	--	--	--	--	--	--
07-21-80	--	--	--	--	--	--
07-28-80	5.4×10^8	9.2×10^6	2.4×10^5	--	--	--
08-04-80	2.4×10^8	1.7×10^6	1.4×10^4	--	--	--
08-18-80	8.4×10^8	3.3×10^6	3.3×10^4	--	--	--
09-02-80	4.9×10^8	4.5×10^5	2.3×10^4	1.3×10^5	--	--
09-15-80	1.7×10^8	4.5×10^5	3.3×10^4	4.5×10^3	--	--
10-06-80	2.3×10^8	3.3×10^4	4.9×10^5	1.8×10^3	--	--
10-13-80	2.4×10^8	2.0×10^5	4.9×10^4	7.0×10^4	--	--
10-27-80	4.9×10^8	--	2.3×10^4	1.7×10^4	--	2.3×10^3

TABLE F-2 FECAL COLIFORM (MPN/100 ml)

Sample Date	Raw Feed	Aerobic Effluent	Anaerobic Effluent	Aerobic Mixed Liquor	Control Effluent	Shipment
03-31-80	4.5×10^5	--	--	--	7.0×10^6	--
04-14-80	4.9×10^7	--	--	--	1.7×10^6	--
06-16-80	--	--	--	--	--	--
06-30-80	1.2×10^8	2.1×10^5	7.8×10^4	--	--	--
07-14-80	--	--	--	--	--	--
07-28-80	1.4×10^8	1.4×10^6	4.9×10^4	--	--	--
08-04-80	9.2×10^7	--	1.4×10^4	--	--	--
08-18-80	7.8×10^7	7.8×10^5	1.7×10^4	--	--	--
09-02-80	4.5×10^7	2.0×10^5	2.3×10^4	7.8×10^4	--	--
09-15-80	4.5×10^7	2.0×10^5	1.1×10^5	4.5×10^3	--	--
10-06-80	2.0×10^7	1.7×10^4	4.9×10^5	2.0×10^3	--	--
10-13-80	3.3×10^7	2.0×10^5	4.9×10^4	3.3×10^4	--	--
10-27-80	2.0×10^7	--	2.3×10^4	3.3×10^4	--	2.0×10^3

TABLE F-3 FECAL STREPTOCOCCI (BACTERIA/100 ml)

Sample Date	Raw Feed	Aerobic Effluent	Anaerobic Effluent	Aerobic Mixed Liquor	Control Effluent	Shipment
03-31-80	7.3×10^4	--	--	--	8.2×10^3	--
04-14-80	1.7×10^7	--	--	--	1.5×10^6	--
06-16-80	--	--	--	--	--	--
06-30-80	1.4×10^7	2.1×10^5	2.0×10^4	--	--	--
07-14-80	--	--	--	--	--	--
07-21-80	--	--	--	--	--	--
07-28-80	2.2×10^7	1.4×10^6	4.9×10^4	--	--	--
08-04-80	--	--	--	--	--	--
08-18-80	1.0×10^7	1.1×10^6	5.5×10^5	--	--	--
09-02-80	1.5×10^7	7.0×10^4	4.0×10^5	1.2×10^5	--	--
09-15-80	8.8×10^6	9.0×10^3	1.3×10^6	3.5×10^3	--	--
10-06-80	5.4×10^6	2.6×10^4	3.9×10^5	2.8×10^4	--	--
10-13-80	1.2×10^7	2.9×10^4	1.0×10^6	5.6×10^4	--	--
10-27-80	1.0×10^7	--	2.1×10^5	8.7×10^4	--	1.0×10^3

TABLE F-4 *Salmonella* Sp-- (MPN/100 ml)

Sample Date	Raw Feed	Aerobic Effluent	Anaerobic Effluent	Aerobic Mixed Liquor	Control Effluent	Shipment
03-31-80	15.0	--	--	--	2.4	--
04-14-80	56.0	--	--	--	41.0	--
06-16-80	--	--	--	--	--	--
06-30-80	1100.0	< 0.3	21.0	--	--	--
07-14-80	--	--	--	--	--	--
07-21-80	--	--	--	--	--	--
07-28-80	16.0	4.0	21.0	--	--	--
08-04-80	93.0	4.0	93.0	--	--	--
08-18-80	43.0	9.1	240.0	--	--	--
09-02-80	39.0	< 0.3	460.0	< 0.3	--	--
09-15-80	15.0	< 0.3	43.0	< 0.3	--	--
10-06-80	43.0	< 0.3	9.3	< 0.3	--	--
10-13-80	39.0	< 0.3	75.0	< 0.3	--	--
10-27-80	460.0	--	23.0	< 0.3	--	< 0.3

TABLE F-5 ASCARIS

Sample Date	Raw Feed		Aerobic Effluent		Aerobic Mixed Liquor		Anaerobic Effluent		Control Effluent	
	OVA/60 g	Viable	OVA/60 g	Viable	OVA/60 g	Viable	OVA/60 g	Viable	OVA/60 g	Viable
03-31-80	2	1	-	-	-	-	-	-	19	2
04-14-80	2	0	-	-	-	-	-	-	5	2
	OVA/100 g	Viable	OVA/100 g	Viable	OVA 100 g	Viable	OVA/100 g	Viable	OVA 100 g	Viable
06-16-80	0	-	0	-	-	-	0	-	-	-
06-30-80	-	0	1	1	-	-	0	0	-	-
07-14-80	0	0	0	0	-	-	0	0	-	-
07-21-80	0	0	0	0	-	-	0	0	-	-
07-28-80	0	-	0	-	-	-	0	-	-	-
08-04-80	0	-	0	-	-	-	0	-	-	-
08-18-80	1	0	0	0	-	-	0	0	-	-
09-02-80	0	0	0	0	0	0	1	0	-	-
09-15-80	0	0	0	0	0	0	0	0	-	-
10-06-80	0	0	0	0	0	0	0	0	-	-
10-13-80	0	0	1	0	0	0	0	0	-	-

TABLE F-6 TOXOCARA

Sample Date	Raw Feed		Aerobic Effluent		Aerobic Mixed Liquor		Anaerobic Effluent		Control Effluent	
	OVA/60 g	Viable	OVA/60 g	Viable	OVA/60 g	Viable	OVA/60 g	Viable	OVA/60 g	Viable
03-31-80	1	0	-	-	-	-	-	-	5	0
04-14-80	3	1	-	-	-	-	-	-	1	1
	OVA/100 g	Viable	OVA/100 g	Viable	OVA/100 g	Viable	OVA/100 g	Viable	OVA/100 g	Viable
06-16-80	0	-	0	-	-	-	0	-	-	-
06-30-80	-	0	3	0	-	-	0	0	-	-
07-14-80	0	0	0	0	-	-	0	0	-	-
07-21-80	0	0	0	0	-	-	0	0	-	-
07-28-80	0	-	0	-	-	-	0	-	-	-
08-04-80	0	-	0	-	-	-	0	-	-	-
08-18-80	0	0	1	0	-	-	1	0	-	-
09-02-80	0	0	0	0	1	0	3	0	-	-
09-15-80	1	0	0	0	0	0	1	0	-	-
10-06-80	0	0	2	0	0	0	0	0	-	-
10-13-80	0	0	0	0	0	0	1	0	-	-

TABLE F-7 VIRUS (PFU/100 ml)

Sample Date	Raw Feed	Aerobic Effluent	Anaerobic Effluent	Control Effluent	Aerobic Mixed Liquor
03-31-80	145.0	--	--	2.0	--
04-14-80	250.0	--	--	50.0	--
06-16-80	67.0	< 2.0	8.0	--	--
06-30-80	258.0	< 2.2	< 2.2	--	--
07-14-80	--	--	--	--	--
07-21-80	758.0	< 1.5	< 2.2	--	--
07-28-80	425.0	< 2.0	2.0	--	--
08-04-80	830.0	< 1.25	< 1.25	--	--
08-18-80	1160.0	< 2.0	< 2.0	--	--
09-02-80	1364.0	< 2.0	< 2.0	--	--
09-15-80	1464.0	< 2.0	< 2.0	--	< 2.0
10-06-80	828.0	< 2.0	< 2.0	--	< 2.0
10-13-80	360.0	< 2.0	< 2.0	--	< 2.0
10-27-80	1108.0	< 2.0	< 2.0	--	< 2.0